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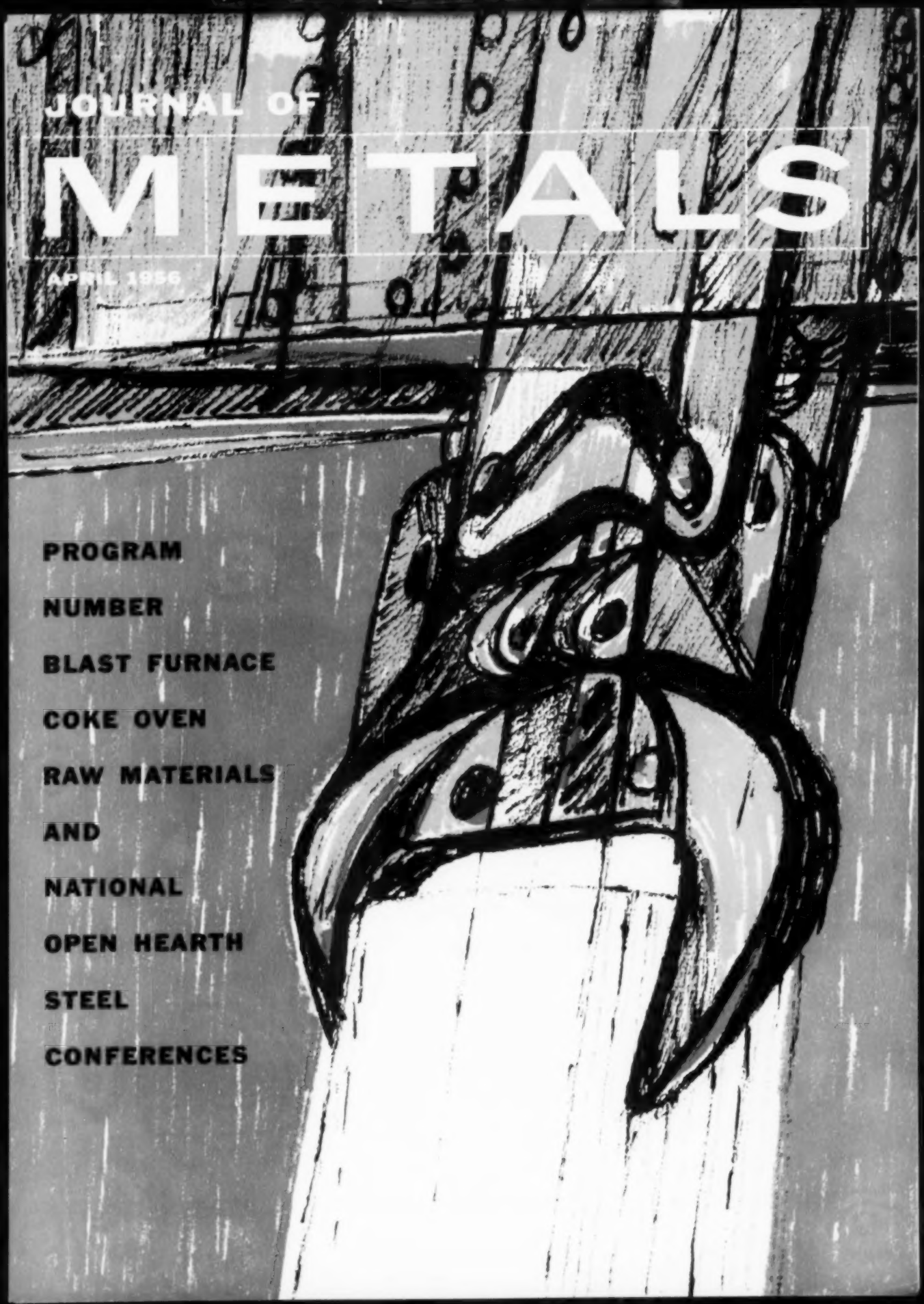
METALS

APRIL 1956



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COVER

Blast Furnace and open hearth steelmaking operations provided the inspiration for artist Harry Brocke's introduction to the 39th annual steelmaking conferences to be held in Cincinnati April 9 through 12. Program details will be found on pages 411 through 414.

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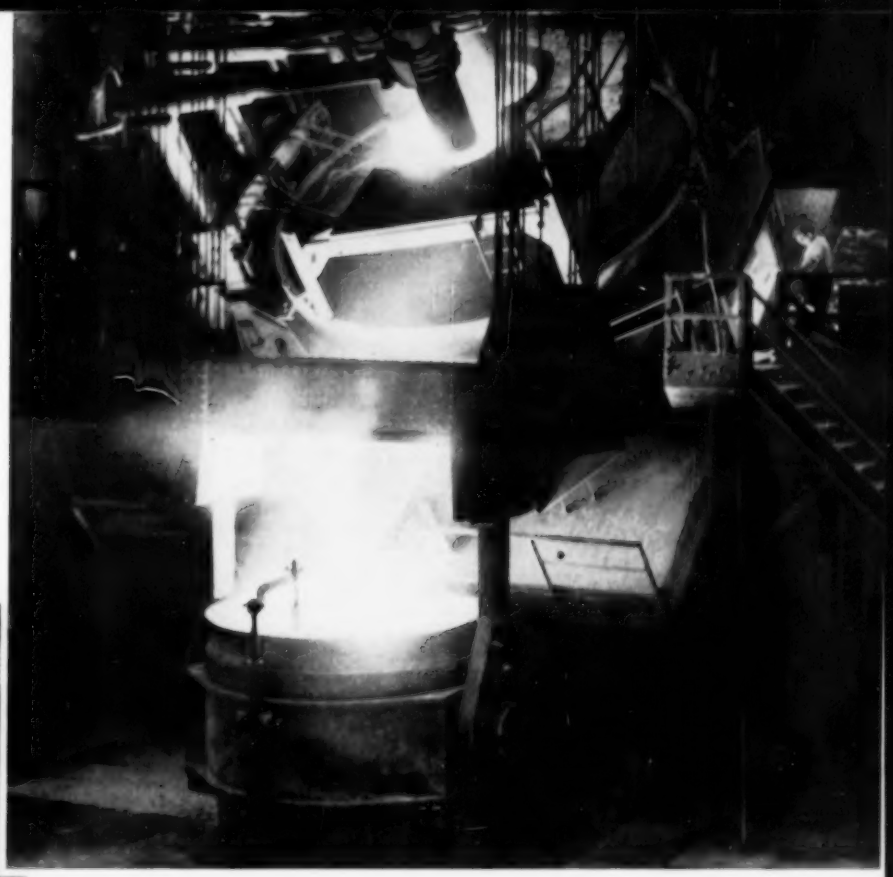

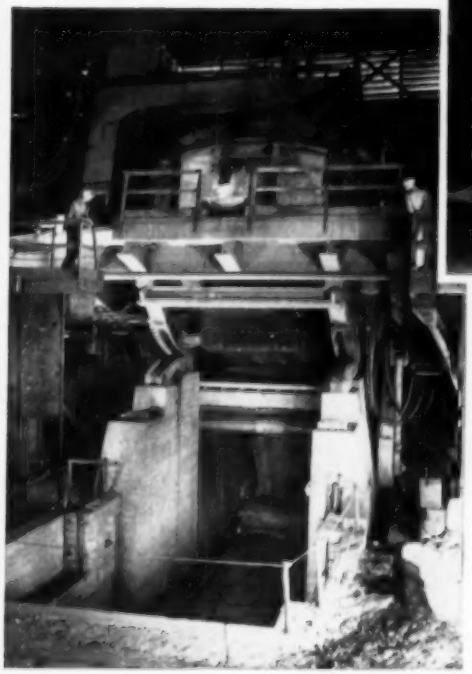

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Minerals Yearbook, 1952, Area Reports, Volume III, by the staff of the U. S. Bureau of Mines, *Superintendent of Documents,* U. S. Government Printing Office, Washington 25, D. C., $3.75, 1050 pp., 1955.—*Yearbook* material has increased to the point where it is impractical to publish it under one cover. This third volume completes the Yearbook for 1952. Volume I, **Metals and Minerals (Except Fuels)** ($4.00) contains chapters on mineral commodities, a chapter reviewing these industries, a statistical summary and recapitulation, and chapters on mining technology, metallurgical technology, and employment and injuries. Volume II, **Fuels** ($2.25) consists of chapters on each mineral-fuel commodity, as well as chapters reviewing the industry as a whole, a statistical summary, and an employment and injury presentation. Volume III is made up of chapters covering each of the 48 States, plus chapters on Alaska, the Territories and island possessions in the Pacific and the Caribbean, including the Canal Zone. It also has a chapter recapitulating its statistics in summary form on a regional basis and another presenting employment and injury data regionally.

Steels for the User, R. T. Rolfe, *Philosophical Library,* $10.00, 399 pp., 3rd ed., 1956.—This book was written "to bridge the gap between science and practice for carbon steels in industry." Although it deals substantially "with carbon steels, alloy steels are discussed for duties for which carbon steels are unsuitable, as with nitriding steels and those for high temperature service." The author is consultant to the British firm, W. H. Allen Sons & Co. Ltd. This third edition has been enlarged and brought up to date.

F B I Register 1956, *Kelly's Directories Ltd.* and *Iliffe & Sons Ltd.,* 42s. Od. ($5.90), post free, 1110 pp., 1955.—Published for the Federation of British Industries. The 1956 register is a comprehensive guide to a cross section of British industries, and lists the products and services of over 7000 member firms. Among the features of this edition are French, German, and Spanish sections, alphabetical listings of firms, their addresses, and products and services, a trade association index, a glossary of brands and trade names, and trade mark reproductions.

Speaking Can Be Easy for Engineers, *Engineers' Council for Professional Development,* 50¢, discounts for 100 or more copies, printed in 2 colors.—In order to aid engineers in preparing and delivering effective oral presentations and in conducting interesting meetings, ECPD has issued a second printing of this pocket-size illustrated manual. Newer methods such as visual aids and microphone techniques are discussed as well as selecting the type of presentation, planning, tips for the effective chairman, handling questions, and conducting panel discussions.

Nuclear Physics, by Alex E. S. Green, *McGraw-Hill Book Co. Inc.,* $9.00, 535 pp., 1955.—A comprehensive introduction to the field, the background material of atomic physics is reviewed in this book which is primarily concerned with theories and experiments relating to the behavior, characteristics, and internal structure of nuclei. Among the major topics discussed are instruments and methods, experimental results and interpretation, systematics and semi-empirical theory, and nuclear theory. In order that there be a basis of understanding for the discussions on theory, the essentials of quantum mechanics are presented in one chapter.

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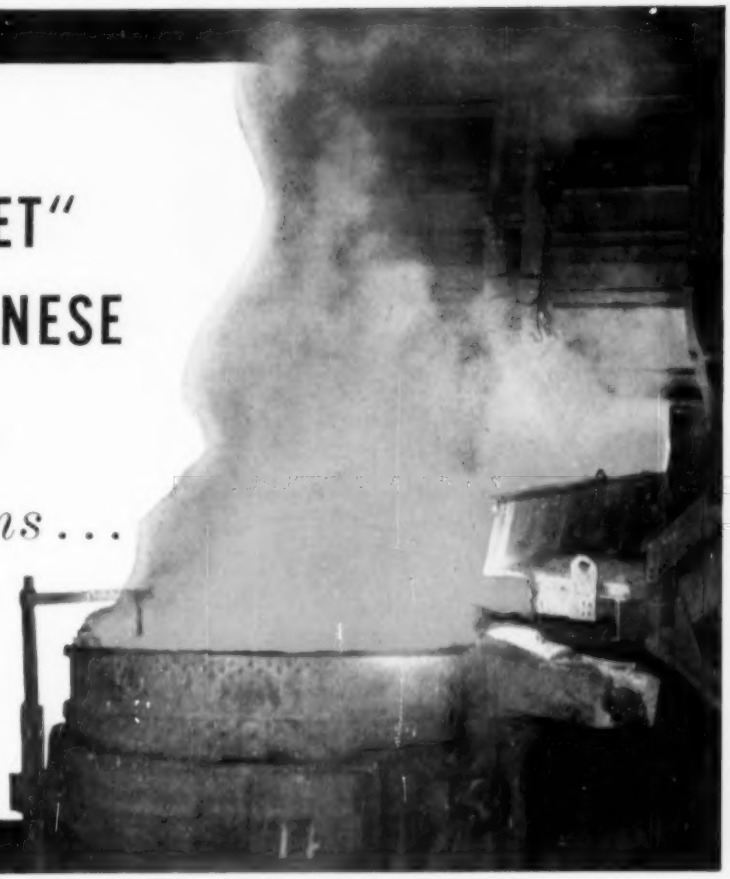

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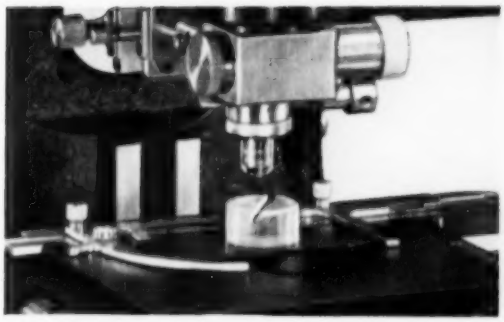

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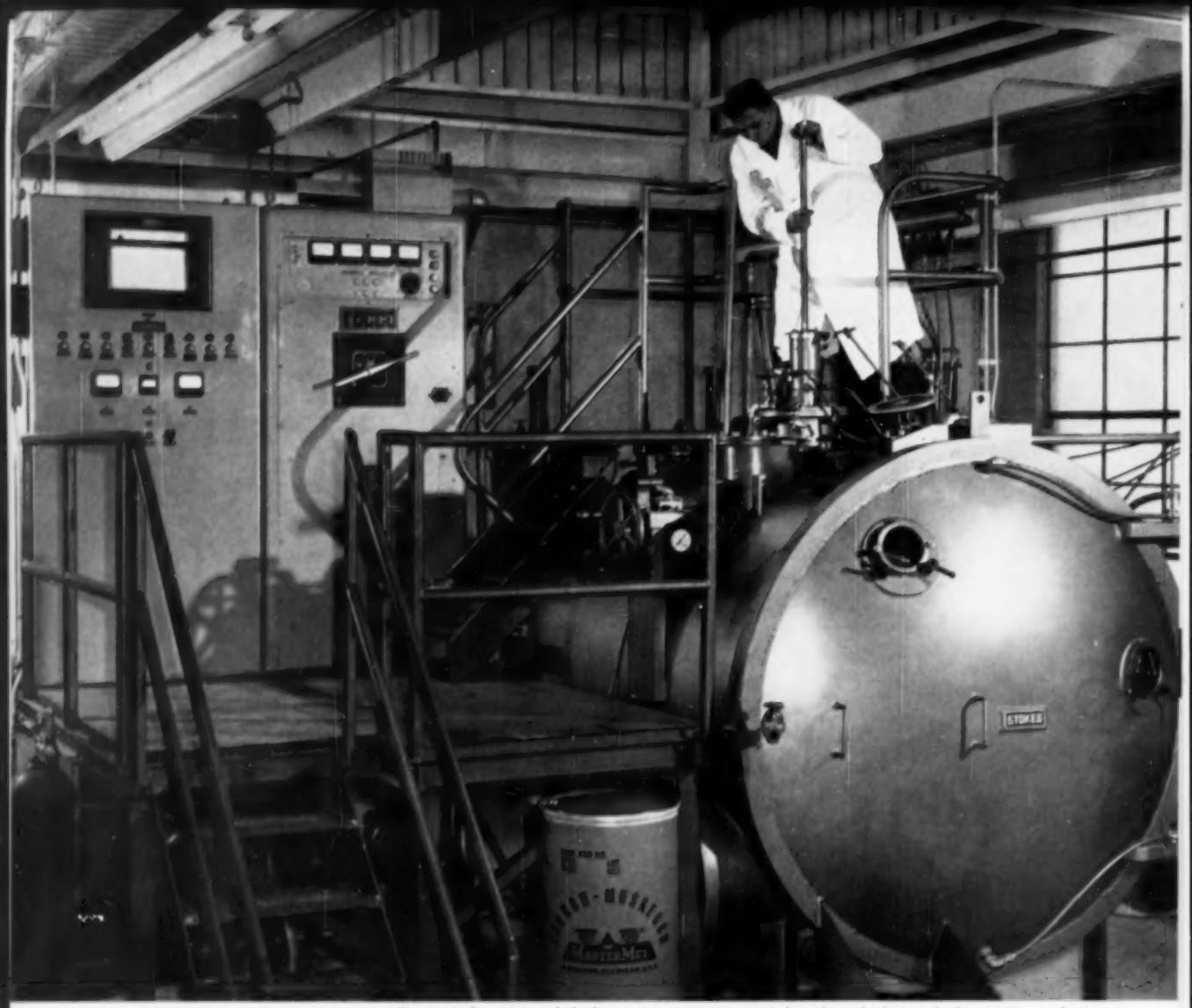

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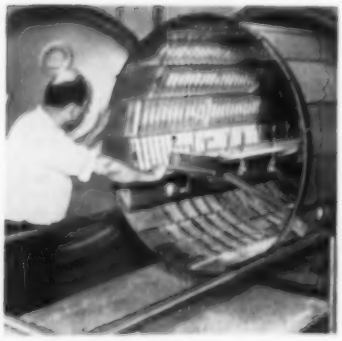

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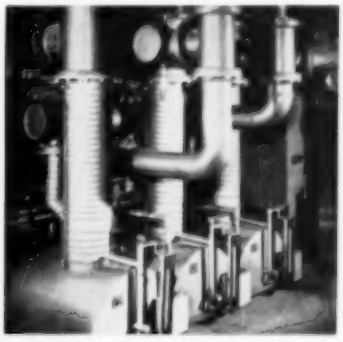

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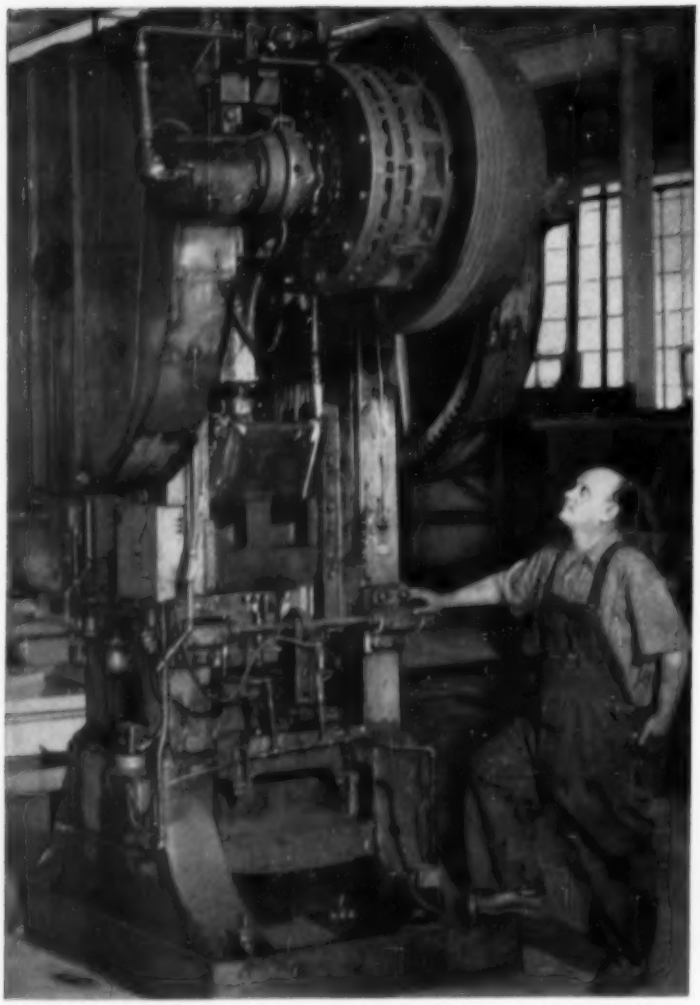
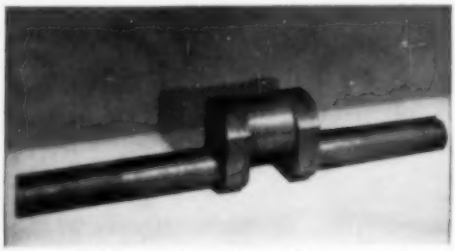
Powder Metal Presses—Catalog 810

STOKES

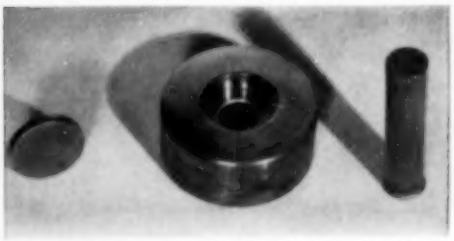


Output up...costs down in plant operating eight presses with Ductile Cast Iron dies, shafts, gears, drums, shoes and the like. State Foundry and Machine Co., Cedar Grove, Wisc., licensed by Inco to produce Ductile Cast Iron, turns out replacements that far outlast previously used materials.

Breakage problem solved. Ductile Cast Iron used on all 8 presses for backshafts. 5′ long and 6″ at widest diameter, with 1″ air hole in center bore, Ductile Iron units need no 8-hour replacement jobs every two months.



Longer life comes from strength and toughness of Ductile Cast Iron. Yet you can readily machine the fine-grained, wear-resistant Ductile Cast Iron used for this heavy-duty crankshaft.



Still good after stamping 875,000 blanks (left) into cases (right). This Ductile Cast Iron die, oil quenched from 1750°F, and stress-relieved at 375°F, develops 55-58 Rockwell C.

Engineers extend life of press parts... up to 18 times with Ductile Cast Iron

IMPRESSIVE RECORDS come from eight 135-ton presses that stamp out 20-mm cartridge cases.

1. Where tool steel dies averaged forty to sixty thousand cases . . .

875,000 cases are now punched out by Ductile Cast Iron dies.

2. Where steel backshafts supporting 3000-pound clutch assemblies failed in about two months . . .

Ductile Cast Iron backshafts have so far served 10 months.

3. Where gray iron brake drums lasted six months maximum . . .

Ductile Cast Iron replacements still operate after 18 months.

Other advantages

As press parts of cast iron and steel wore out or broke, Ductile Cast Iron replacements took over. That reduced downtime, production costs and maintenance, too.

Despite its high wear resistance, Ductile Cast Iron is easy to machine. This advantage saves both time and labor . . . a factor to consider in selecting material for almost any application.

Now replacing more costly materials in many fields, Ductile Cast Iron behaves better in the shop as well as on the job. Get the full story of this economical iron. It's several times stronger than gray cast iron and up to 12 times tougher. Send for a copy of "DUCTILE IRON, The Cast Iron THAT CAN BE BENT!" It's filled with helpful data. Write for your copy now.

ductile iron . . . the cast iron that can be twisted and bent

The INTERNATIONAL NICKEL COMPANY, Inc.
67 Wall Street, New York 5, N. Y.

REPORTER

1955 World Steel Record

A record total of 294 million net tons of steel ingots were produced during 1955 according to the American Iron and Steel Institute. This is an increase of 39 million tons over the previous record set in 1953. For the U.S., tables showing coke-oven and steel mill capacities as of Jan. 1, 1956 are found on pp. 394 and 396 of this issue.

Current U. S. Production at Peak Levels

The steel industry of the U.S. continues to outpace itself. Following the monthly record set in January, February's output exceeded any previous February and was the fifth consecutive month in which production was more than 10 million tons! March output gives every indication of being the sixth such month, and the industry appears optomistic over second quarter prospects.

Industry Expands to Meet Heavy Demand

The most recently announced expansion plans of the U.S. steel industry are those of the Youngstown Sheet & Tube Co., which is to expand its ingot capacity by 1 million tons to 6.7 million tons. Although no new blast furnaces are to be installed, the firm is expanding its rolling capacity in both the Chicago and Youngstown districts. In addition to the 2 million ton expansion at Sparrows Point, Md., Bethlehem Steel Co. is increasing ingot capacity at both Lackawanna, N.Y., and Bethlehem, Pa., by a total of 1 million tons. The U.S. Steel Corp. has plans for expanding open hearth and rolling capacity at the Gary, Ind., works and the South Chicago, Ill., works by a total of 1.2 million ingot tons. Additional sintering facilities are planned at both plants.

Export-Import Bank Aids South American Steel Expansion

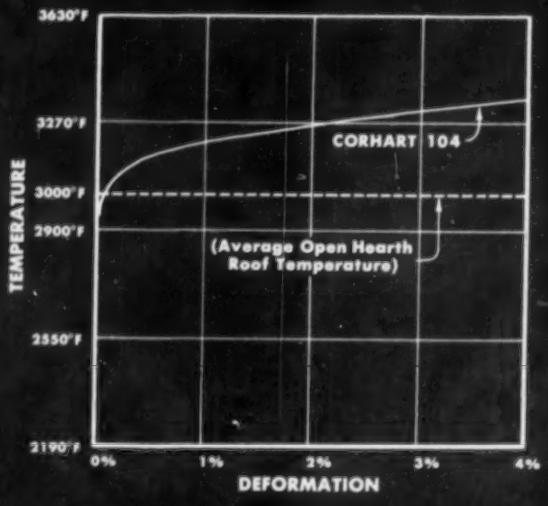
The Export-Import Bank of Washington, D.C., has recently made three loans for the purchase of American equipment and technical know-how by South American steel mills. The Cia. Siderurgica National at Volta Redonda, Brazil, the largest steel mill in the continent, is receiving $35 million to expand its new integrated plant from an ingot capacity of 750,000 tons to 1 million tons. The Sociedad Mixta Siderurgica Argentina has obtained $60 million for Argentina's first integrated steel plant. The mill of some 550,000 tons of ingot capacity is being built at San Nicholas, a deep water port on the Parana River. In Chile the Cia. de Acero del Pacifica S.A., is receiving $3.35 million to finance the purchase of a hot-strip mill for its 350,000-ton integrated plant located on the ocean near Concepcion. The construction of both the Brazilian and Chilean mills has been heavily financed during the past ten years by previous Export-Import Bank loans. The Koppers Co. has served as a technical consultant on both these projects, while Armco International Corp. and Arthur G. McKee & Co. are consultants on the Argentine plant.

OPEN HEARTH OPERATORS—

Would 100°F Higher Roof Temperatures Make Money for You?

BECAUSE Corhart 104 Electrocast refractory castings are poured at 4400°F., because Corhart 104 has high hot strength, because current open-hearth roof tests of Corhart 104 are definitely encouraging—we believe sprung roofs reinforced with Corhart 104 will permit higher roof temperatures . . . we believe higher roof temperatures will make money for you.

May we discuss Corhart 104 with you? Write! Corhart Refractories Co., *Incorporated*, 1640 West Lee Street, Louisville 10, Kentucky, U.S.A. Telephone — Cypress 4471.

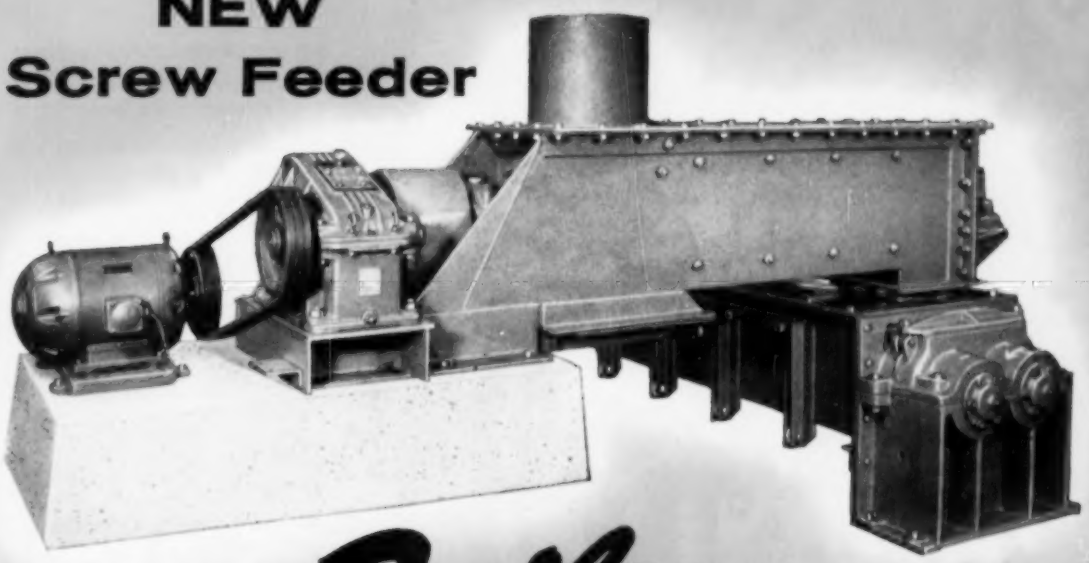


QUALITY ECONOMY ENDURANCE

CORHART 104 ELECTROCAST REFRACTORY

The words "CORHART" and "ELECTROCAST" are registered Trade Marks which indicate manufacture by Corhart Refractories Company, Incorporated

NEW Screw Feeder



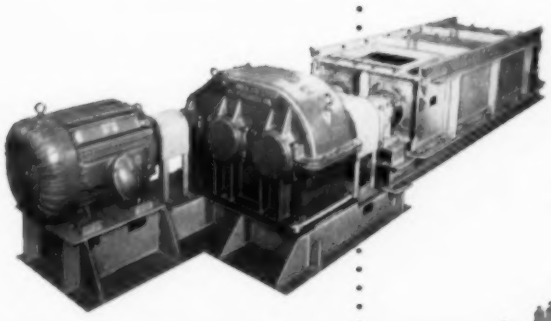
MAKES Bailey PUG MILLS

EVEN MORE EFFECTIVE IN SINTERING PLANT AND BLAST FURNACE DUST CATCHER SERVICE

The new Bailey Screw Feeder is effective for flow regulation and conveying of flue dust, ore fines and various other materials. An outstanding feature is that it maintains uniform flow, even when irregular feeding may be caused by "hanging" of material in dust catcher or a sudden furnace "slip." The feeder speeds the sintering process and assures substantial savings through reduced handling costs.

BAILEY PUG MILLS were developed for low-cost processing of greater tonnages of more uniform sintered products. They are built for continuous service, in capacities from 100 to 400 tons per hour.

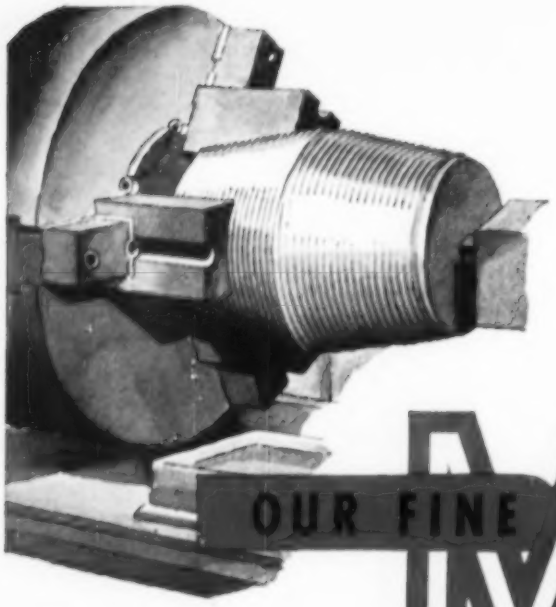
Write for Bulletins



This Bailey Double Shaft Pug Mill is equipped with a double helical gear reduction unit. Types of Bailey Pug Mills available include single and double shaft types, with direct or rope drives.

WILLIAM M. Bailey COMPANY
ENGINEERS
LEADERSHIP THROUGH QUALITY

1221 BANKSVILLE ROAD PITTSBURGH 16, PA



MILLING NIPPLE THREADS

AS PARTNERS IN YOUR PROGRESS . . .

OUR FINE MACHINING – is a *plus* factor!

Finishing operations on GLC electrodes, anodes and mold stock are performed with the utmost precision. A strict system of gaging and inspection is required at this stage.

The craftsmanlike spirit of our milling, machining and inspection personnel is a distinctive *plus factor* in the efficiency of GLC carbon and graphite products.

The high degree of integration between discoveries in our research laboratories, refinements in processing raw materials, and improved manufacturing techniques is further assurance of excellent product performance.

ELECTRODE GLC® DIVISION

Great Lakes Carbon Corporation

GRAPHITE ELECTRODES, ANODES, MOLDS and SPECIALTIES

ADMINISTRATIVE OFFICE: 18 East 48th Street, New York 17, N. Y. PLANTS: Niagara Falls, N. Y., Morganton, N. C. OTHER OFFICES: Niagara Falls, N. Y., Oak Park, Ill., Pittsburgh, Pa. SALES AGENTS: J. B. Hayes Company, Birmingham, Ala., George O. O'Hara, Wilmington, Cal. SALES AGENTS IN OTHER COUNTRIES: Great Northern Carbon & Chemical Co., Ltd., Montreal, Canada; Great Eastern Carbon & Chemical Co., Inc., Chiyoda-Ku, Tokyo, Japan

Drift of Things

(Ed. Note: Engineers Joint Council is one of the professional activities in which AIME participates, but its work is not as widely known as it deserves to be. We asked long-time AIME member Paul Lange—who also happens to be EJC Secretary—to help rectify this lack of information. Here it is.)

ENGINEERS Joint Council is primarily an organization established *by* the profession *for service to* the profession. One primary purpose is to work toward greater unity within the engineering profession, and results here show up when the present EJC structure is compared with its background. The grandfather of EJC was the engineering council of the national technical societies formed in 1917. This in turn expanded into the American Engineering Council of the Federated Engineering Societies in 1920, and AEC operated until dissolved in 1940. Engineers Joint Conference, composed of the presidents and secretaries of the five major engineering societies was formed in 1940, and grew into Engineers Joint Council in 1945. The American Engineering Council differed materially from the present EJC in that the members of AEC board were not directly responsive to the boards of their own activities. The Board of Directors of EJC, however, must be individually members of their own societies board. This provides the continuity or link of authority between the supporting organization and EJC.

At present the Council represents through its constituent, associate, and affiliate members an engineering membership of approximately 220,000.

CONSTITUENT SOCIETIES

American Society of Civil Engineers
American Institute of Mining, Metallurgical and Petroleum Engineers
The American Society of Mechanical Engineers
American Water Works Association
American Institute of Electrical Engineers
The Society of Naval Architects and Marine Engineers
American Society for Engineering Education
The American Society of Refrigerating Engineers
American Institute of Chemical Engineers

ASSOCIATE SOCIETIES

The American Institute of Industrial Engineers
American Association of Agricultural Engineers

AFFILIATE SOCIETIES

Los Angeles Council of Engineering Societies
Kentucky Society of Professional Engineers

The expansion of EJC has been slow but steady. The slowness is entirely accounted for by the careful planning which has gone into the gradual reorganization of its constitution. The present growth pattern of the Council stems from 1949 when an exploratory group with representation from 15 engineering societies undertook a two-year study. As a result, constitutional changes were made and additional societies were offered the opportunity to take part in EJC activities. The National Society of Professional Engineers were a member of the exploratory group but declined to become a member society of EJC because of basic differences in the philosophy of NSPE and the other groups. EJC, however, works closely with NSPE on matters of common interest to the engineering profession.

Many specific accomplishments can be credited to EJC—and there will no doubt be many more as it grows and takes an active part in subjects of interest to *the profession as a whole*. Perhaps the most important recent undertaking was the sponsorship of the Nuclear Engineering and Science Congress in Cleveland in December 1955. This marked the first time in the history of this country that over 20 recognized engineering and scientific organizations made any attempt to cooperate on a national level to promote dissemination of information on a subject of basic interest to all. As a result of this congress, representatives of five of the major engineering societies have met and recommended that an annual congress on Nuclear Engineering be held under the general sponsorship of EJC. This single activity is one of the best examples of the growth of unity among the members of the profession.

EJC Objectives

- *To advance the general welfare of mankind through the available resources and creative ability of the engineering profession.*
- *To promote cooperation among the various branches of the engineering profession.*
- *To advance the science and profession of engineering.*
- *To develop sound public policies respecting national and international affairs wherein the engineering profession can be helpful through the services of the members of the engineering profession.*

How it works

- *Act as an advisory and coordinating agency to seek and study matters of mutual interest to the constituent societies of Council and to recommend parallel action by them.*
- *Represent the constituent societies of the Council in instance in which constituent societies deem joint representation to be desirable.*
- *Administer on behalf of the engineering profession, those activities authorized by a majority of the constituent societies of the Council.*

Another example is the General Assembly of EJC. The first was held in 1955 with an attendance of 300, and the second, in January 1956, had an attendance of 500 for a two-day program. Next year coverage by sessions will be extended to give still more coverage of subjects that are of interest to the profession as a whole.

The basic committees of the Council, operating under the authority of the Board of Directors, include those on Constitution and Bylaws, Finance, and Membership. These provide the foundation for policy and operation of the Council. The operating committees are those which are charged with specific tasks. These tasks represent problems which require solutions. If solutions do not result, at least considered study yields results which can guide others in finding their own solutions. Among such committees is the Engineering Manpower Commission, in operation since 1951. Its activities have been widely felt in the profession in the past five years and it has provided the government with the necessary background information on the need for a utilization of engineers "in industry and in the armed forces." Commission policy is determined by the EJC Board. The Committee on Employment Conditions is another of this operating group. For the past year and a half it has been preparing a report on "Professional Standards and Employment Conditions" which has just been accepted by the EJC Board of Directors and which will be published shortly.

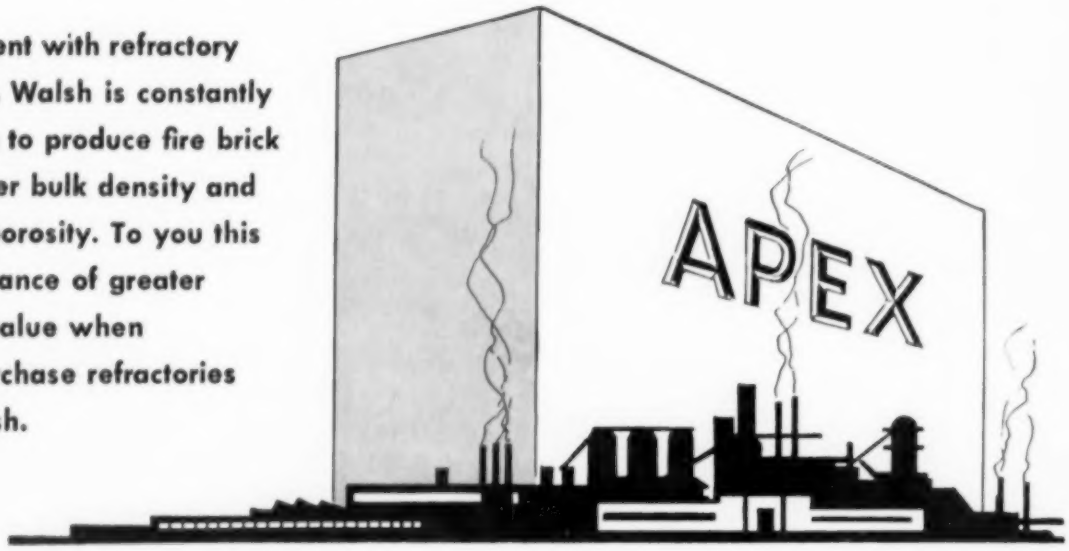
E. Paul Lange

Walsh points the Way...

TOWARD A NEW HORIZON in REFRACTORY *Performance*

An Open Letter to the Steel Industry...

consistent with refractory quality, Walsh is constantly striving to produce fire brick of higher bulk density and lower porosity. To you this is assurance of greater dollar value when you purchase refractories by Walsh.



Specialists in fire brick of high bulk density and low porosity

WALSH REFRACTORIES CORPORATION

101 FERRY STREET • ST. LOUIS 7, MISSOURI

FOR OVER 60 YEARS MANUFACTURERS OF HIGH GRADE REFRACTORIES

WESTINGHOUSE SAVES $18,043 with USS "T-1" STEEL

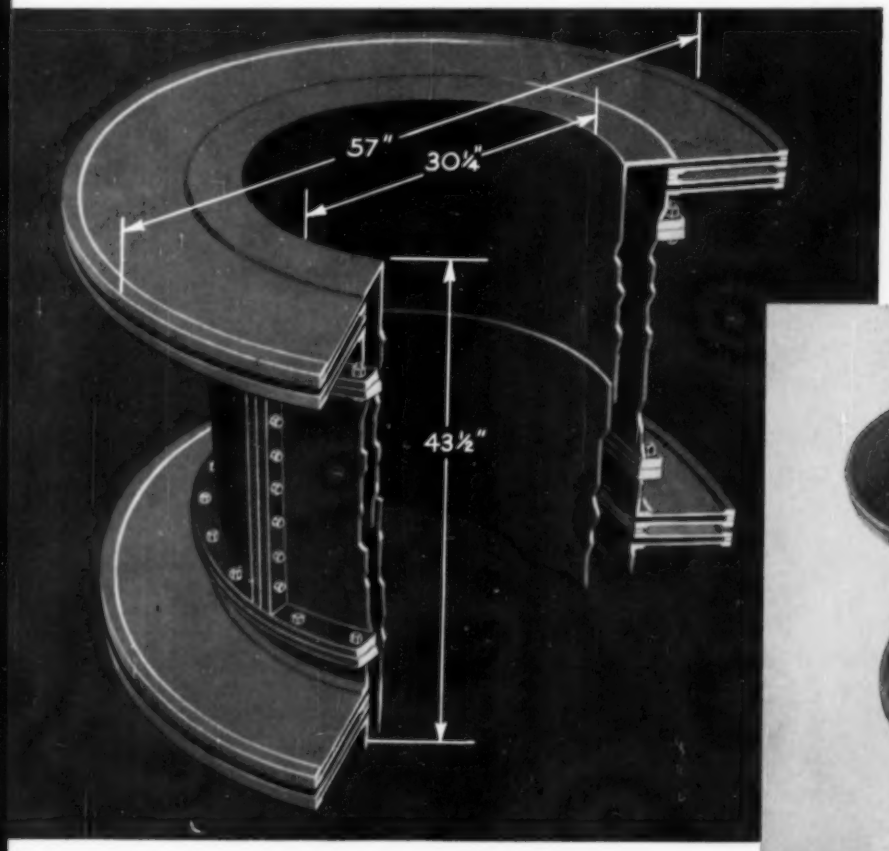
The Sunnyvale, California plant of Westinghouse Electric Corporation controls vibration of huge wind-tunnel air compressors with unusual supporting struts. Steel bellows that flex, both up-and-down and sideways, absorb and isolate the tremendous vibration in these powerful machines. Westinghouse lopped an impressive $18,043 off the cost of these bellows by switching to USS "T-1" Steel.

"T-1" costs less to machine. It costs less to weld. To top it off, "T-1" *costs less to buy* than the steel previously used. Yet it is plenty tough and strong enough to meet the rugged physical requirements.

NEW WAYS TO SAVE MONEY

No other alloy steel can be used in *so many ways* to save money or improve products. Already—and "T-1" is still a relatively new steel—it has been used with great success in rotating machines, earth-moving equipment, towers, pressure vessels, mining machines, printing presses, and other heavy-duty applications.

Think of USS "T-1" when *you* need very high tensile strength (105,000 psi.) and yield strength (90,000 psi.) . . . when you need good creep rupture strength at high temperatures . . . extraordinary toughness at sub-zero temperatures . . . resistance to abrasion, impact, and abuse. All or any of these properties, plus good weldability, are yours in "T-1"! For information write to United States Steel, Room 5274, Pittsburgh 30, Pa.



STEEL BELLOWS SOAK UP VIBRATION. Here is one of the struts that support each air compressor. Two steel bellows—at the top and at the bottom of the central cylindrical section—flex and absorb the shock and stress of heavy vibration from the compressor. Tough, strong, steel was needed for the bellows. USS "T-1" does the job, and saves money for Westinghouse Electric Corporation.

UNITED STATES STEEL CORPORATION, PITTSBURGH • COLUMBIA-GENEVA STEEL DIVISION, SAN FRANCISCO • TENNESSEE COAL & IRON DIVISION, FAIRFIELD, ALA.
UNITED STATES STEEL SUPPLY DIVISION, WAREHOUSE DISTRIBUTORS, COAST-TO-COAST • UNITED STATES STEEL EXPORT COMPANY, NEW YORK

USS "T-1" CONSTRUCTIONAL ALLOY STEEL

USS

UNITED STATES STEEL

Research-Cottrell Precipitator

- Open Hearths
- Iron Ore Sintering Machines
- Ferro-Manganese Blast Furnaces
- Scarfing Machines

Take a look inside the horizontal flow precipitator on the next page. This is the type of Cottrell used for cleaning gases coming from open hearths, iron ore sintering machines, ferro-manganese blast furnaces, as well as scarfing machines and electric furnaces.

Although it differs in design from the Research-Cottrell blast furnace precipitator, this Cottrell has the same basic advantages—handles any volume of gas at any collection efficiency up to almost 100%. Maintenance and power costs are low, draft loss is only a few tenths of an inch of water, and the precipitator is designed and constructed for many years of heavy-duty, all-weather service.

In addition to these major advantages, a few more design features are shown in the cutaway drawing on the next page.

1 Rapping puffs prevented by automatic and continuous cleaning of collecting electrodes with Magnetic Impulse Rapper (patents pending).

2 Plumb-bob discharge electrodes are individually weighted and positioned by a steadying frame for maximum efficiency.

3 Hopper baffle prevents gas sneakage around electrodes.

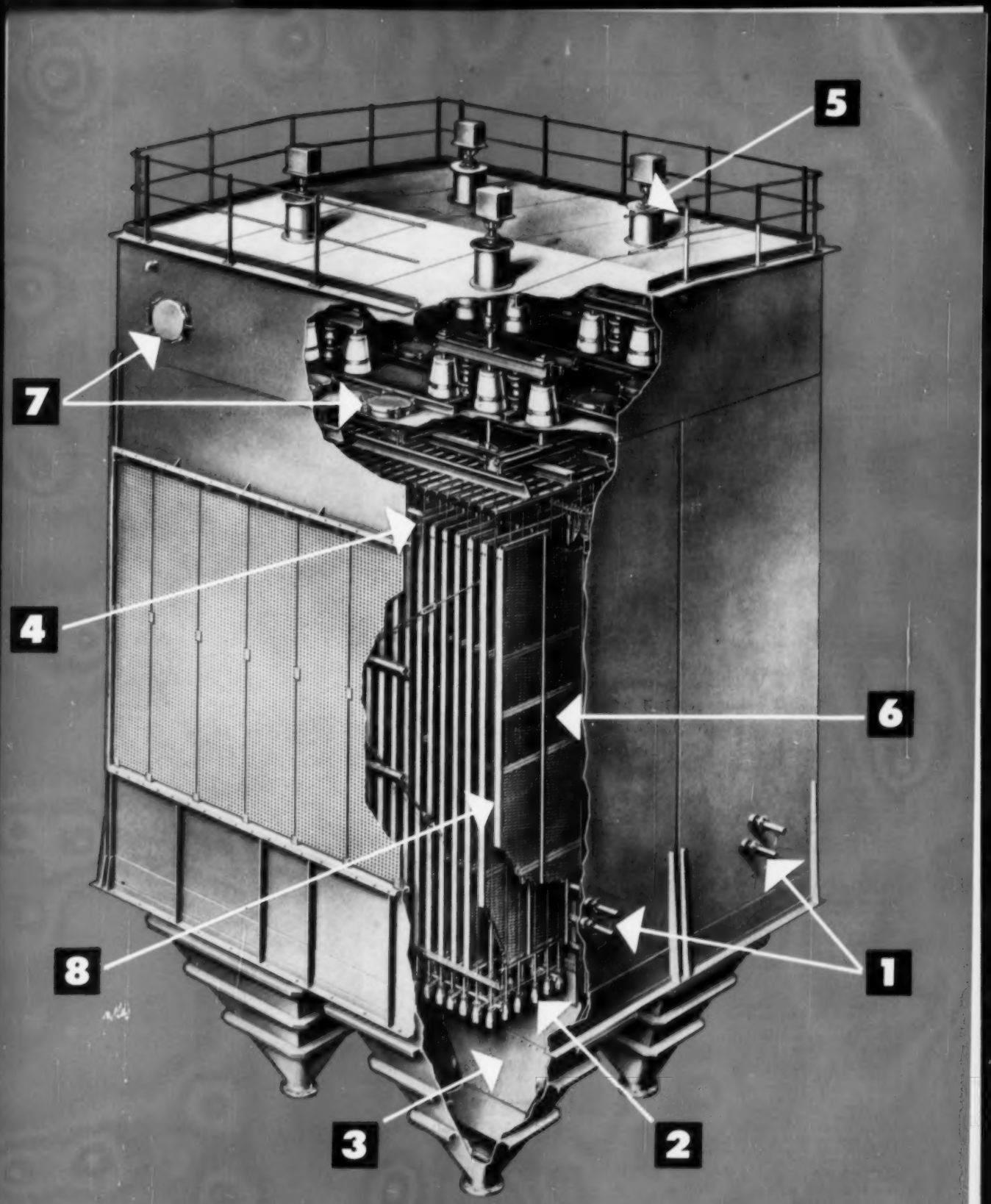
4 Hook-type collecting electrode hangers, quickly installed, insure uniform distribution of rapper vibration throughout entire collecting surface.

5 Continuous, automatic discharge electrode rapping insures optimum performance.

6 No moving parts in gas stream —minimizes maintenance.

7 Easy access to high tension equipment.

8 End and intermediate baffles provide quiescent zones and prevent re-entrainment of collected dust.



Research-Cottrell, Inc.

A Wholly Owned Subsidiary of Research Corporation

Main Office and Plant: Bound Brook, N. J. • 405 Lexington Ave., New York 17, N. Y. • Grant Building, Pittsburgh 19, Pa.

228 N. La Salle St., Chicago 1, Ill. • 111 Sutter Bldg., San Francisco 4, Cal.

Annual Steel Capacity (Ingots and Steel for Castings) As of Jan. 1, 1956

Company	Open Hearth		Bessemer		Electric and Crucible		Total Capacity, Net Tons
	No.	Capacity, Net Tons	No.	Capacity, Net Tons	No.	Capacity, Net Tons	
Alan Wood Steel Co.	8	625,000					625,000
Alco Products Inc.	3	103,000			1	2,160	105,160
Allegheny Ludlum Steel Corp.	5	312,000			20	552,200	864,200
American Compressed Steel Corp.					1	21,600	21,600
Armco Steel Corp.	25	2,978,000			9	432,000	3,410,000
*Sheffield Steel Div.	14	1,440,000			2	300,000	1,740,000
Atlantic Steel Co.	3	188,000			2	262,000	450,000
Babcock & Wilcox Co.					4	229,450	229,450
Baldwin-Lima-Hamilton Corp.	5	169,920			1†	40	169,960
Barium Steel Corp.:							
*Industrial Forge & Steel Co.	2	48,600					48,600
*Phoenix Iron & Steel Co.	10	804,000			1	46,000	850,000
Berkman Co., Louis							
*Ohio River Steel Div.	4	136,080					136,080
Bethlehem Steel Corp.:							
*Bethlehem Steel Co.	124	18,556,000	3	336,000	4	158,000	19,050,000
*Bethlehem Pacific Coast Steel Corp.	10	498,000			3	452,000	950,000
Borg-Warner Corp.:							
*Ingersoll Steel Div.					4	64,000	64,000
*Ingersoll Products Div.					2	100,000	100,000
Bracburn Alloy Steel Corp.					2	20,730	20,730
Byers Co., A. M.					2	90,000	90,000
Cabot Shops Inc.					1	12,000	12,000
Cameron Iron Works Inc.					2	58,800	58,800
Carpenter Steel Co.					6	73,700	73,700
Colorado Fuel & Iron Corp.	27	2,279,500					2,279,500
Roebling's Sons Corp., J. A.	9	235,000					235,000
Columbia Tool Steel Co.					2	6,600	6,600
Continental Steel Corp.	5	394,000					394,000
Copperweld Steel Co.					7	618,380	618,380
Crucible Steel Co. of America	9	1,044,000			17	379,400	1,423,400
Detroit Steel Corp.	14	1,290,000					1,290,000
Eastern Stainless Steel Corp.					4	50,000	50,000
Edgewater Steel Co.	3	117,600					117,600
Empire Steel Corp.	7	500,000					500,000
Erie Forge & Steel Corp.	5	234,000					234,000
Finkl & Sons Co., A.					2	33,600	33,600
Firth Sterling Inc.					3	20,040	20,040
Ford Motor Co.	10	1,649,300			5	228,120	1,877,420
Granite City Steel Co.	7	1,080,000					1,080,000
Green River Steel Corp.					2	179,400	179,400
Harrisburg Steel Corp.	3	100,750					100,750
Heppenstall Co.	2	50,470			1	5,080	55,550
Hooter Steel Corp.					1	12,000	12,000
Inland Steel Co.	40	5,200,000					5,200,000
International Harvester Co.	11	1,000,000					1,000,000
Isaacson Iron Works					2	102,000	102,000
Jessop Steel Co.					4	33,490	33,490
Jones & Laughlin Steel Corp.	37	5,583,000	3	582,000	1	1,500	6,166,500
Joslyn Mfg. & Supply Co.					3	37,500	37,500
Judson Steel Corp.	3	76,500					76,500
Kaiser Steel Corp.	9	1,536,000					1,536,000
Keystone Steel & Wire Co.	4	425,000					425,000
Kilby Steel Co.					1	34,020	34,020
Knoxville Iron Co.					2	38,000	38,000
Laclede Steel Co.	4	500,000					500,000
Latrobe Steel Co.					5	24,000	24,000
Le Tourneau Inc., R. G.					3	83,100	83,100
Lone Star Steel Co.	4	550,000					550,000
Lukens Steel Co.	12	750,000					750,000
McLouth Steel Corp.					9‡	1,380,000‡	1,380,000
Merritt-Chapman & Scott Corp.:							
*Milton Steel Products Div.					3	90,000	90,000
*Newport Steel Corp.	7	375,300			3	333,200	708,500
Mesta Machine Co.	4	85,000			1	20,000	105,000
Midvale-Heppenstall Co.	4	184,970			7	140,030	325,000
National Forge & Ordnance Co.					3	25,000	25,000
National Steel Corp.:							
*Great Lakes Steel Corp.	17	3,200,000‡	2				3,200,000
*Weirton Steel Co.	13	2,800,000‡	2				2,800,000
National Supply Co.					3	50,200	50,200
Newport News Shipbuilding & Dry Dock Co.					1	12,000	12,000
Northeastern Steel Corp.	3	188,280			3	114,920	303,200
Northwest Steel Rolling Mills, Inc.					2	46,000	46,000
Northwestern Steel & Wire Co.					5	825,000	825,000
Oregon Steel Mills					3	120,000	120,000
Pacific States Steel Corp.	3	181,770					181,770
Pittsburgh Steel Co.	12	1,320,000					1,320,000
Porter Co. Inc., H. K.:							
*Connors Steel Div.					3	115,000	115,000
*Disston Div. (Henry)					2	25,000	25,000
*Vulcan Crucible Steel Co.					2	9,600	9,600
Republic Steel Corp.	78	8,222,000	2	665,000	26	1,375,000	10,262,000
Rotary Electric Steel Co.					6	300,000	300,000
Sharon Steel Corp.	16	1,691,000			2	72,000	1,763,000
Simonds Saw & Steel Co.					3	21,600	21,600
Southwest Steel Rolling Mills					1	45,000	45,000
Texas Steel Co.					3	70,450	70,450
Timken Roller Bearing Co.					9	700,000	700,000
Union Electric Steel Corp.					2	26,760	26,760
United States Steel Corp.:							
*United States Steel Corp. (Central Operations)	177	24,941,000	8**	1,284,000	9	369,000	26,594,000
*American Steel & Wire Div.	26	2,275,000					2,275,000
*Columbia-Geneva Steel Div.	18	2,539,000					2,539,000
*National Tube Div.	18	2,700,000	6	1,110,000			3,810,000
*Tennessee Coal & Iron Div.	23	3,997,000	3‡				3,997,000
Universal-Cyclops Steel Corp.					5	70,160	70,160
Vanadium-Alloys Steel Co.					4	12,000	12,000
*Colonial Steel Co.					2	30,000	30,000
Washburn Wire Co.	4	93,000					93,000
West Virginia Steel & Mfg. Co.					1	78,840	78,840
Wheeling Steel Corp.	11	1,560,000	2	570,000			2,130,000
Wickwire Brothers Inc.					1	21,380	21,380
Youngstown Sheet and Tube Co.	41	5,510,000	2	240,000			5,750,000
Grand Total	911	112,317,040	33††	4,787,000	267‡†	11,259,050	128,363,090

* Indicates subsidiary. † Crucible furnace. ‡ Includes 3 oxygen converters, annual capacity: 540,000 tons. § Used in melting charge for open hearth furnaces. ** Includes 3 converters used only in melting charge for open hearth furnaces. †† Includes 10 converters used only in melting charge for open hearth furnaces. ‡† Includes 1 crucible furnace, annual capacity: 40 tons. See acknowledgment, p. 396.

Electric furnace roofs at

THE TIMKEN ROLLER BEARING COMPANY

are bonded with

TAYCO-40
SILICA CEMENT

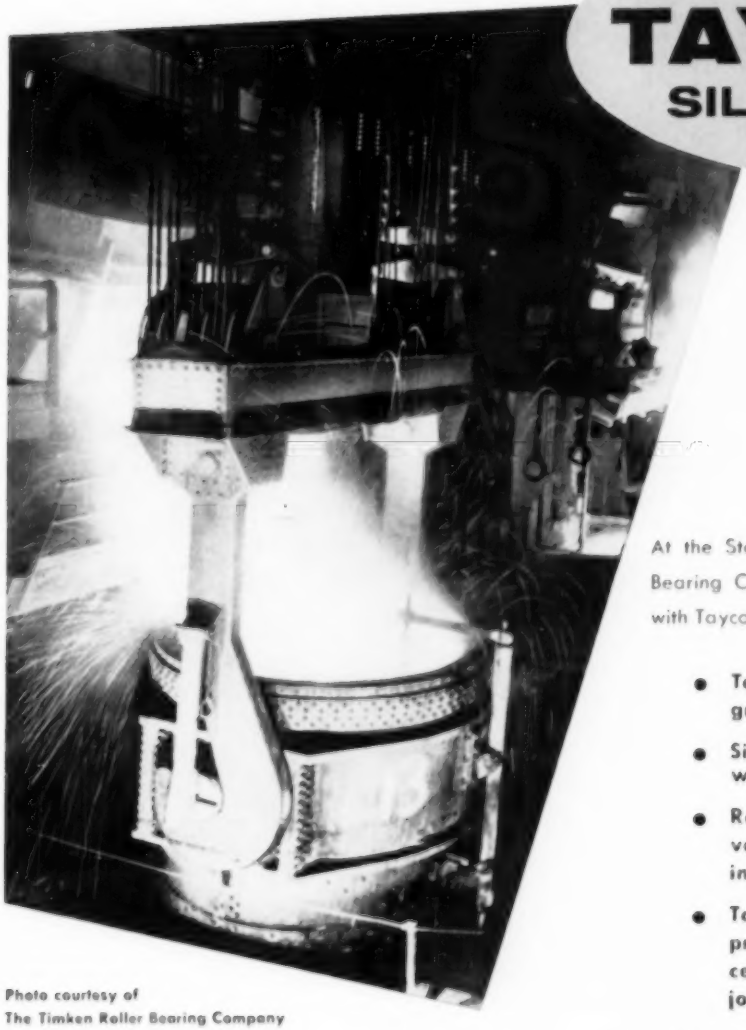


Photo courtesy of
The Timken Roller Bearing Company

At the Steel and Tube Division of The Timken Roller Bearing Company, electric arc furnace roofs are laid with Tayco-40 Silica Cement. The advantages are many:

- **Tayco-40 is nearly as refractory as the best grades of silica or super-duty silica brick.**
- **Silica brick and shapes are more easily fitted with all voids and irregularities well filled.**
- **Roof life is prolonged. Thin, tight joints prevent brick from slipping out of place when in service. Spalling is retarded.**
- **Tayco-40 has excellent water retention properties. It is the most workable silica cement obtainable. Less cement is used; joints are thinner, tighter.**

Tayco-40 is used and endorsed by superintendents of leading steel mills for lengthening the life of silica electric furnace roofs and side walls; for open-hearth furnace roofs, and all other places in open-hearths where silica brick are used. Try Tayco-40 for your next rebuild. Detailed data given in Bulletin No. 507. Ask your Taylor Field Engineer or write direct for your copy.

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Annual Capacity of Blast Furnaces as of Jan. 1, 1956

Company	No. of Stacks	Total Capacity, Net Tons
Alan Wood Steel Co.	2	454,800
Armco Steel Corp.:	6	1,978,000
*Sheffield Steel Div.	1	360,000
Barium Steel Corp.:		
*Phoenix Iron and Steel Co.	1	200,000
Berkman Co., Louis	1	136,800
Bethlehem Steel Co.	33	12,830,000†
Colorado Fuel and Iron Corp.	7	1,463,600
Crucible Steel Co. of America	3	895,000
Detroit Steel Corp.	2	768,700
Eastern Gas and Fuel Associates	1	195,000
Ford Motor Co.	3	1,199,400
Globe Iron Co.	1	100,000
Granite City Steel Co.	2	450,000
Inland Steel Co.	8	3,011,200
Interlake Iron Corp.	6	1,555,000
International Harvester Co.	3	731,000
Jackson Iron & Steel Co.	1	95,000
Jones & Laughlin Steel Corp.	13	4,587,000
Kaiser Steel Corp.	3	1,314,000
Lavino & Co., E. J.	2‡	120,000
Lone Star Steel Co.	1	385,000
McLouth Steel Co.	1	483,500
National Steel Corp.:		
*Great Lakes Steel Corp.	4	2,050,000
*Hanna Furnace Corp.	4	850,000
*Weirton Steel Co.	4	2,100,000
New Jersey Zinc Co.	2§	112,000
Pittsburgh Coke & Chemical Co.	3	836,500
Pittsburgh Steel Co.	3	980,000
Republic Steel Corp.	22	7,276,000
Sharon Steel Corp.	3	814,400
Shenango Furnace Co.	2	445,450
Merritt-Chapman & Scott Corp.:		
*Tennessee Products & Chemical Corp.	3	217,740
Tonawanda Iron Div.	1	165,000
United States Pipe & Foundry Co.	4	491,710
United States Steel Corp.:		
*United States Steel Corp. (Central Operations)	53**	19,159,500
*American Steel & Wire Div.	6	1,693,000
*Columbia-Geneva Steel Div.	5	1,804,200
*National Tube Div.	9	3,255,100
*Tennessee Coal & Iron Div.	9††	3,209,000
Wheeling Steel Corp.	6	1,800,000
Woodward Iron Co.	4	772,630
Youngstown Sheet & Tube Co.	13	4,140,000
Grand Total	261‡‡	85,485,230

* Indicates subsidiary. † Includes 216,000 tons ferroalloys capacity. ‡ Ferromanganese only. § Spiegeleisen only. ** Includes 322,800 tons ferroalloys capacity. †† Includes 39,000 tons ferroalloys capacity. ‡‡ Includes 809,800 tons ferroalloys capacity.

Annual Coke Capacity as of Jan. 1, 1956

Company	Beehive		Other		Total Capacity, Net Tons
	No. of Ovens	Capacity, Net Tons	No. of Ovens	Capacity, Net Tons	
Alan Wood Steel Co.			151	600,000	600,000
Armco Steel Corp.			186	1,057,000	1,057,000
*Sheffield Steel Div.			62	318,000	318,000
Bethlehem Steel Co.			2,208	11,450,000	11,450,000
Colorado Fuel and Iron Corp.			266	1,220,000	1,220,000
Crucible Steel Co. of America			213	831,600	831,600
Detroit Steel Corp.			108	550,000	550,000
Eastern Gas and Fuel Associates			108	664,000	664,000
Ford Motor Co.			220	1,307,200	1,307,200
Granite City Steel Co.			76	450,000	450,000
Inland Steel Co.			418	2,143,400	2,143,400
Interlake Iron Corp.			390	1,494,000	1,494,000
International Harvester Corp.			148	664,300	664,300
Jones & Laughlin Steel Corp.			831	3,937,000	3,937,000
Kaiser Steel Corp.	297	100,000	225	1,006,000	1,106,000
Lone Star Steel Co.			78	438,000	438,000
National Steel Corp.:					
*Great Lakes Steel Corp.			216	1,600,000	1,600,000
*Hanna Furnace Corp.			126	622,000†	622,000†
*Weirton Coal Co.	136	120,000			120,000
*Weirton Steel Co.			253	1,620,000	1,620,000
Pittsburgh Coke & Chemical Co.			140	1,000,000	1,000,000
Pittsburgh Steel Co.	320	228,000	74	500,000	728,000
Republic Steel Corp.	296	215,000	1,179	6,310,000†	6,525,000†
Sharon Steel Corp.			60	225,000	225,000
*Carpentertown Coal & Coke Co.	586	375,000			375,000
Merritt-Chapman & Scott Corp.:					
*Tennessee Products & Chemical Corp.			44	251,500	251,500
United States Pipe & Foundry Co.			150	754,100	754,100
United States Steel Corp.:					
*United States Steel Corp. (Central Operations)	1,733	1,054,000	3,043	14,650,800	15,704,800
*American Steel & Wire Div.			295	1,418,100	1,418,100
*Columbia-Geneva Steel Div.			308	1,345,700	1,345,700
*National Tube Div.			354	1,602,200	1,602,200
*Tennessee Coal & Iron Div.			558	3,032,500	3,032,500
Wheeling Steel Corp.			314	1,720,000	1,720,000
Woodward Iron Co.			256	938,000	938,000
Youngstown Sheet and Tube Co.			705	3,696,000	3,696,000
Grand Total	3,367	2,092,000	13,763	69,416,400	71,508,400

* Indicates subsidiary. † Indicates 50 pct of coke capacity of the Donner-Hanna Coke Corp., Buffalo.

Acknowledgment is given to the American Iron & Steel Institute for permission to publish these official capacity figures. All data were compiled by AISI, and are correct as of Jan. 1, 1956.

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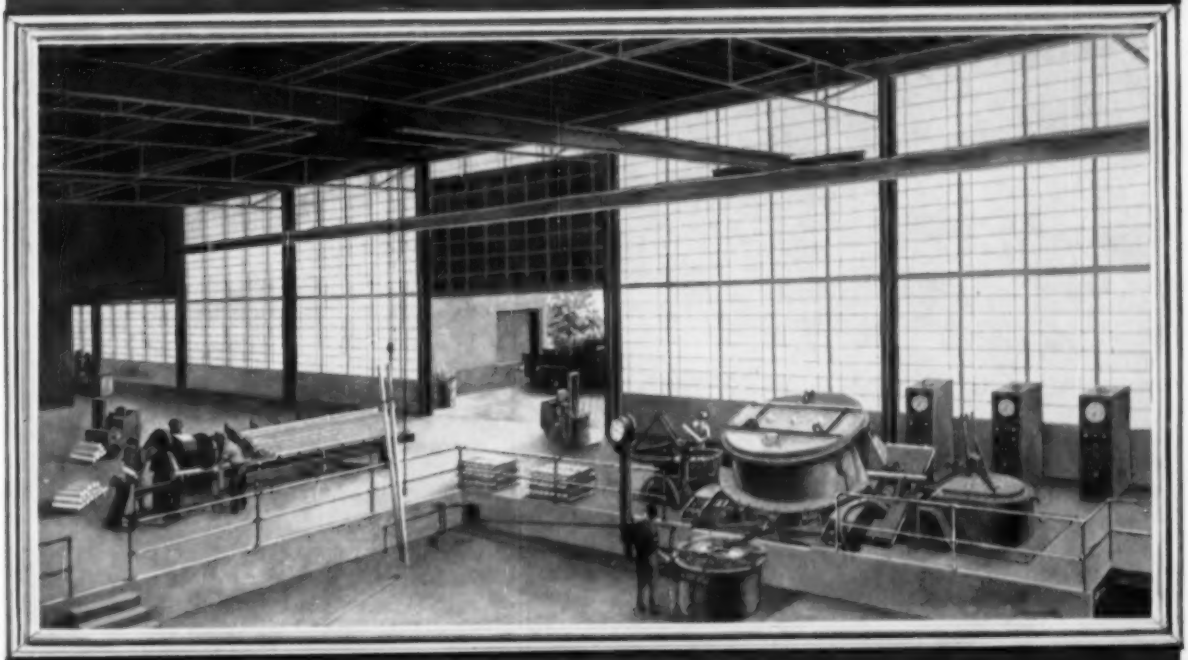

INSTALLATION AT VALLEY METAL PRODUCTS COMPANY, PLAINWELL, MICH.
(SUBSIDIARY OF MUELLER BRASS CO.)

Photograph from an oil painting by J. Gordon White

Manufacturers of "Vampco" architectural life long aluminum alloy extrusions, Valley Metal Products Co., use Ajax furnaces exclusively in their billet casting shop, because these furnaces enable them to produce aluminum alloy billets from selected scrap in the high quality required for their product.

The compact layout of this casting shop, shown in the picture, includes two 166 kw Ajax melting furnaces and one Ajax 10,000 lbs. holding furnace which pours into a semi-continuous casting machine. Operation is continuous. **Production is 750,000 lbs. per month.** Metal losses are below 1%. The holding furnace requires no fluxing or chlorinating. Maintenance is low. Working conditions are comfortable and permit full utilization of all productive efforts.

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HEAT MORE STEEL with MORGAN-ISLEY

The Morgan-Isley system offers you a better means of heating ingots with straight blast furnace gas, coke oven gas, natural gas or oil.

The schematic shows the flow of combustion air and flue gases through the regenerators and soaking pit. The Morgan-Isley system employs vertical regenerators. It eliminates regenerator capacity under the crane runway thus freeing this valuable area for heating steel.

CCC-48

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National Open Hearth Steel Committee

Local Section Activities

Chicago Section

• Activities of the **Chicago Section** were varied and successful. Phil Smidt's Restaurant was the scene of the spring dinner meeting on May 23, 1955, with 114 members attending. Technical chairman for the program was Earl Pierce, of South Works, Carnegie-Illinois Steel Corp. He led the discussions covering open hearth factors which influence product surface and problems associated with open hearth chemistry.

The annual golf party was held at Midlothian Country Club on Sept. 13, 1955. Two hundred actually played golf and 415 arrived for the dinner.

Highlight of the fall dinner meeting on Oct. 17, 1955, at Phil Smidt's Restaurant, was the report on European steelmaking practices by Lew Berner and Mike Tannenbaum of the Inland Steel Co. They presented first hand observations from their trip of the preceding summer.

For the all-day off-the-record meeting on March 14, 1956, the Chicago group chose the Del Prado Hotel. Subjects discussed were: resurfacing bottoms; pouring aisle refractories; aluminum control in the manufacture of fully aluminum killed steel; and mold coatings. The $100 annual prize award just established for the best paper on some phase of open hearth practice, was presented for the first time to L. E. Kraay. His paper was entitled *Resurfacing Open Hearth Furnace Bottoms.*

The section plans a spring dinner on May 7 at Phil Smidt's Restaurant at which time Courtney Sorrels of Gary Works, U. S. Steel Corp., will serve as technical chairman.

Officers for 1956 are: T. D. Hess, Youngstown Sheet & Tube Co., Chairman; H. Erler, Gary Works, U. S. Steel Corp., Vice Chairman; and M. Nickel, Wisconsin Steel Works, International Harvester Co.

T. D. HESS

Youngstown Sheet & Tube Co.,
East Chicago, Ind.
Chairman, Chicago Section

W. M. MONTGOMERY

U. S. Steel Corp., Torrance, Calif.
Chairman, Western Section

Western Section

• During the last year the **Western Section** met four times at the Rodger Young Auditorium. The attendance averaged approximately 50.

The dinner-business meeting on Sept. 21, 1955, under the chairmanship of K. L. Grant, Bethlehem Pacific Coast Steel Corp., featured a speech on *Open Hearth Improvement* by L. W. Murphy of Pacific Coast Steel Corp. On Nov. 16, 1955, W. T. Purvance of U.S. Steel Corp., presented a talk on a new approach to open hearth maintenance. Mr. Purvance also showed slides on rebuilding an open hearth furnace and moving the furnace back into place. Chairman for the meeting was W. M. Montgomery, U. S. Steel.

Tom Jones, chairman of the Jan. 18 meeting this year, also served as featured speaker. Mr. Jones, of National Supply Co., discussed the *Use of Refractory Gun on Electric Furnace Bottom.* James E. Fredennick, ISD, Kaiser Steel Corp., the principal speaker at the session on Mar. 21, was introduced

by technical chairman W. F. Bowers, Jr., also of Kaiser. Mr. Fredennick reported on the application and development of the use of mechanically capped steel in his company.

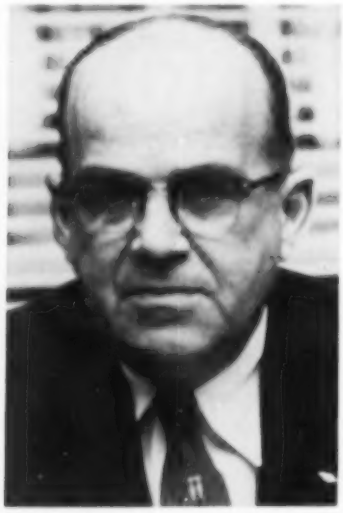
Future plans include a meeting on May 16, 1956 at the Rodger Young Auditorium. C. C. Wissman of the Southwest Steel Rolling Mills, has been chosen technical chairman.

Southwestern Section

• The usual spring meeting of the **Southwestern Section** was held in St. Louis on February 11, 1956 at the Hotel Lennox. Approximately 125 persons registered and the majority of them were present at the all-day technical session. Attendance at the fellowship dinner which followed was 116. The technical program for the spring meeting was arranged by J. E. Wilbank, Atlantic Steel Co., Atlanta, retiring program chairman for the section.

The fall meeting of the section was held Oct. 6–7, 1955 in Kansas City. In addition to the all-day technical session, the fall meeting had an additional day, Oct. 6, which was devoted to a plant visit of the Sheffield Steel Company. The technical session with headquarters at the Hotel President, was followed by a fellowship dinner. The total registration for both functions was 143. The Suppliers' cocktail party, a highlight of the daytime activities at the fall meeting, was capably handled by Henry Day and Norvall Hunthausen.

The election of officers for a two-year term, was held at the February meeting. Those elected were: J. M. Brashear, Lone Star Steel Co., Chairman; K. P. Campbell, ARMCO Steel Corp., Co-Chairman; Henry Day, Valley Dolomite Corp., Secretary-Treasurer; Norvall Hunthausen, Mexico Refractories, Assistant Secretary-Treasurer, and Bill Steinheider, ARMCO Steel, Program Chairman.



J. M. BRASHEAR
Lone Star Steel Co., Lone Star, Texas
Chairman, Southwestern Section

C. W. CONN
Ford Motor Co., Dearborn
Chairman, Detroit Section

Detroit Section

• The **Detroit Section** held their first meeting on February 29 with 129 present, an excellent attendance for the first organization meeting. All of the principal ingot steel producing companies in the area—Ford Motor Co., Great Lakes Steel Corp., Rotary Electric Steel Co. and McLouth Steel Corp.—were well represented.

Chairman W. C. Conn outlined the history of the National Open Hearth Committee. He then called on AIME Secretary Kirkendall, former NOHC Secretary, to discuss the importance of the Open Hearth local sections, as well as the AIME to the metallurgical profession.

Mr. Conn introduced those present at the speakers table, including Bill Spaulding of Great Lakes Steel, Bob Surgeson of Rotary Electric, Paul Lindberg of McLouth and K. D. Cassidy of Ford. They emphasized how pleased their companies were to support the new NOHC section and to have this new service to the steel industry in the Detroit area.

Bill Reilly, one of the early participants in the NOHC Conferences reminisced on the first meetings. He pointed out how far the steel men had advanced in their willingness to exchange information, since the early days. Mr. Reilly felt that much of the progress being made in the steel industry could be attributed to this exchange of information.

Mr. Conn thanked M. J. Smith for his help in acting as chairman of the organization committee, and Harry Clark, secretary of the new section, for his extensive work in arranging for the opening meeting. It was noted that the new section had met

jointly in January with the Detroit Section, AIME, to discuss oxygen in steelmaking.

Before closing the meeting, Mr. Conn announced the appointment of a nominating committee under the chairmanship of Martin E. Groat and a program committee headed by Chairman Paul Lindberg. Future plans include a technical program in about two months, when new officers will be elected.

Northern Ohio Section

● The year 1955 was an active one for the **Northern Ohio Section** with good attendance at both the annual off-the-record technical session and the golf party.

On Tuesday Mar. 1st, 1955, the technical session was held at the Pick-Ohio Hotel in Youngstown with approximately 250 members present. Co-chairmen Bruce Ramage, Youngstown Sheet & Tube Co., and J. F. Beale, Republic Steel Corp., arranged an interesting program. The first speaker, F. W. Rys, Coppers Co. Inc., discussed *Continuous Casting at Atlas Steel Corp.* He was followed by Karl L. Fetters, Youngstown Sheet & Tube, who summarized steelmaking in the last decade. The meeting concluded with a talk by K. F. Waggener, Republic Steel, on *Effects of Auto Pour and Related Pit Problems.*

After the cocktail hour the dinner featured a speech by Harry A. Stuhldreher, assistant to the vice president, U. S. Steel Corp.

The golf party was held at Youngstown Country Club on June 3rd at which time 150 were present for the dinner.

Officers elected for 1956 are: J. Smith, Chairman, and J. F. Beale, Secretary-Treasurer, both of Republic Steel.

JAMES SMITH

Republic Steel Corp., Warren, Ohio
Chairman, Northern Ohio Section

R. W. LEWRY

Detroit Steel Corp., Portsmouth, Ohio
Chairman, Southern Ohio Section

Southern Ohio Section

● For their 19th Annual Conference on Sept. 23, 1955, the **Southern Ohio Section** chose the Deshler-Hilton Hotel in Columbus, Ohio. The 204 members were welcomed by chairman R. W. Lewry, Detroit Steel Corp.

Two technical sessions were arranged. The first, on operating and combustion, featured three papers and a European report. Albert Meihack, Empire Steel Corp., spoke on *Atomization of Fuel Oil with High Pressure Gas.* Discussing blast furnaces, E. R. Kercsmar, Armco Steel Corp., showed how to extend the life of bottle type ladles. J. F. Pollack of Jones & Laughlin Steel Corp., treated the subject, *Application of High Alumina or Super Duty Suspended Fantail Nose Brick.* This meeting concluded with Charles R. Taylor's description of his trip to Europe. Mr. Taylor is associated with Armco.

The practice and quality session was under the leadership of A. P. Woods and W. O. Richmond; both men are with Armco. Among the topics discussed were: factors affecting the basic quality of medium carbon killed steel; ladle nozzle setting cage, and a comparison of chimney type checkers. The general symposium was concerned with *Methods Used to Control Scrapping Molds and Stools.*

Toastmaster for the dinner was H. G. Grim, Heppenstall Co., Pittsburgh, who introduced the featured speaker of the evening, Leo Wolman, Prof. of Economics at Columbia University. Dr. Wolman is also director of the National Bureau of Economic Research.

The section's annual golf outing was held on June 24, 1955. Approximately 56 members participated in the golf activities and 80 attended the dinner, at the Elks Country Club in Portsmouth, Ohio. The 1956 outing is scheduled for June 8th in Ashland, Ky., and the annual meeting will be held again at the Deshler-Hilton Hotel on Oct. 5th, 1956.

Buffalo Section

• The **Buffalo Section** held their meeting at the Royal Connaught Hotel in Hamilton, Ontario, Canada on Nov. 15, 1955, with 233 attending.

In the morning a group of 175 visited the new oxygen steel plant and continuous galvanizing line of the Dominion Foundries & Steel Ltd. which generously provided bus transportation for the trip.

The technical session held in the afternoon was devoted to problems of furnace operating and combustion, pouring and pit practice, and steel quality. Foremen of various plants took an active part in the animated discussions. The evening banquet saw a turnout of 208.

The executive committee elected the following officers for a two-year term: J. L. Walton, Bethlehem Steel Co., Chairman; J. R. Atkinson, Dominion Foundries & Steel Ltd., Vice Chairman; and H. A. Morlock, General Refractories Co., Secretary and Treasurer.

The Buffalo Section's plans for the year include a golf party on June 5, 1956 and the annual meeting on November 13, 1956.

Pittsburgh Section

• Three events were held by the **Pittsburgh Section** during 1955, a dinner-technical meeting, a spring golf party and the annual off-the-record meeting.

The dinner-technical meeting was held in cooperation with the AIME Iron and Steel Div., local section, and was attended by 250 members and guests. John Chipman of the Massachusetts Institute of Technology presented an excellent review of the most recent developments in research on hydrogen in steelmaking.

At the golf party held on June 17, 1955 at Oakmont Country Club, a total of 185 members and guests enjoyed the perfect weather and played golf. S. J. Dougherty served as toastmaster at the evening golf party dinner attended by 325 members. The committee which arranged the details of this party was under the chairmanship of J. T. Meell.

The annual off-the-record meeting was held at the William Penn Hotel on November 4, 1955 with a total registration of 860. As in past years, the off-the-record meeting has been a joint effort in cooperation with all local AIME sections, including Coal, Petroleum, and the Institute of Metals.

Seventy engineering students attended the technical sessions and the Fellowship Dinner as guests of individual members and the NOHC Pittsburgh Section. The general chairman of the meeting was R. J. Murdy, assisted by E. B. Snyder. At the Fellowship Dinner, S. J. Dougherty served as toastmaster and the speaker of the evening was Robert Charpie of the Oakridge National Laboratory. John F. Elliott and Frank W. Luerssen received the F. L. Toy award, and the Student Prize Paper award was presented to Lowell Brenner.

Future events of this section include an ISD dinner meeting scheduled for May 17, 1956. F. D. Richardson from England will be the featured speaker. The golf party will be held June 13, 1956 at the Field Club, Pittsburgh, and the annual off-the-record meeting is slated to take place at the William Penn Hotel on Nov. 1, 1956.

D. L. McBRIDE

U. S. Steel Corp., Pittsburgh
Chairman, Pittsburgh Section

The present officers of the Pittsburgh Section are: D. L. McBride, U. S. Steel Corp., Chairman; R. M. Barnhart, Alco Products Corp., Vice Chairman; C. M. Kay, U. S. Steel, Secretary; C. Longenecker, Blast Furnace & Steel Plant, Treasurer.

Eastern Section

A new slate of officers for the **Eastern Section** was elected at the January Board of Directors meeting. Plans for the 1956 program were made at that time, the first event of the year being a visit to the Alan Wood Steel Co. plant in Conshohocken, Pa. This trip will include stops at the new Plate Mill and Cold Mill as well as the Open Hearth. A luncheon meeting for the group will follow the plant trip.

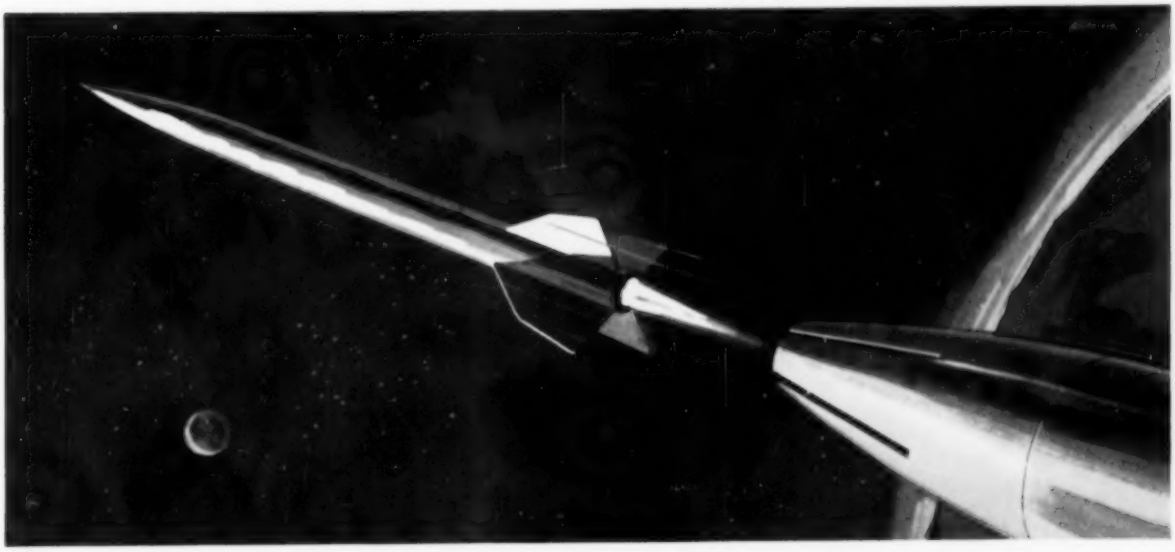
The principal event of the year will be the annual fall meeting scheduled for October 12, 1956. Results of the elections were: Chairman, C. D. Moore, G. & W. H. Corson Inc.; Vice Chairman, G. S. Baldwin, Standard Steel Works Div., Baldwin-Lima-Hamilton Corp.; Directors, R. Mathews, Alan Wood Steel Co., and H. W. Potter, Lukens Steel Co.; Secretary-Treasurer, J. R. Behrman, Alan Wood Steel Co.; Program Committee Chairman, C. B. Jenni, General Steel Castings Corp.

Notable Achievements at JPL

THE WORLD'S ALTITUDE RECORD of 250 miles was established by the WAC-Corporal, used as a second-stage missile fired in flight from the nose of a V-2 Rocket at White Sands in February 1949.

The "Wac" was one of a series of test rockets used by JPL in the development of the Corporal, an operational guided missile.

The technology of this two-stage rocket flight has become the foundation on which to build a globe-girdling satellite.



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NUCLEAR ENGINEERING

The success of these rockets has its roots in basic research in propellants and in the imaginative engineering design of rocket motors. Research on propellants at JPL has run the gamut of oxidizers such as nitric acid, hydrogen peroxide, and the pioneer studies of liquid fluorine. Current interest in many unusual fuels, hydrazine for example, stems directly from JPL work of ten years ago.

The Laboratory's work in propellants is of basic scientific interest and is published in professional journals. Precise redetermination of the heat of dissociation of fluorine, studies of the thermodynamics of the nitric acid family and basic research in combustion are all examples of our many continuing interests.

This work in liquid propellants is paralleled by comparable efforts related to solid propellants, materials and metallurgy.

On the engineering side, studies to improve the design of rocket motors able to handle unusual combustion and heat transfer requirements and the design of auxiliary chemical power units are in progress.

These important experiences provide a natural and firm foundation for our current interest in nuclear propulsion.

We need qualified new people for such activities. If you enjoy the challenging atmosphere of new research, write us today. Please outline your technical interests, qualifications and experience.

CALTECH jpl **JET PROPULSION LABORATORY**

A DIVISION OF CALIFORNIA INSTITUTE OF TECHNOLOGY

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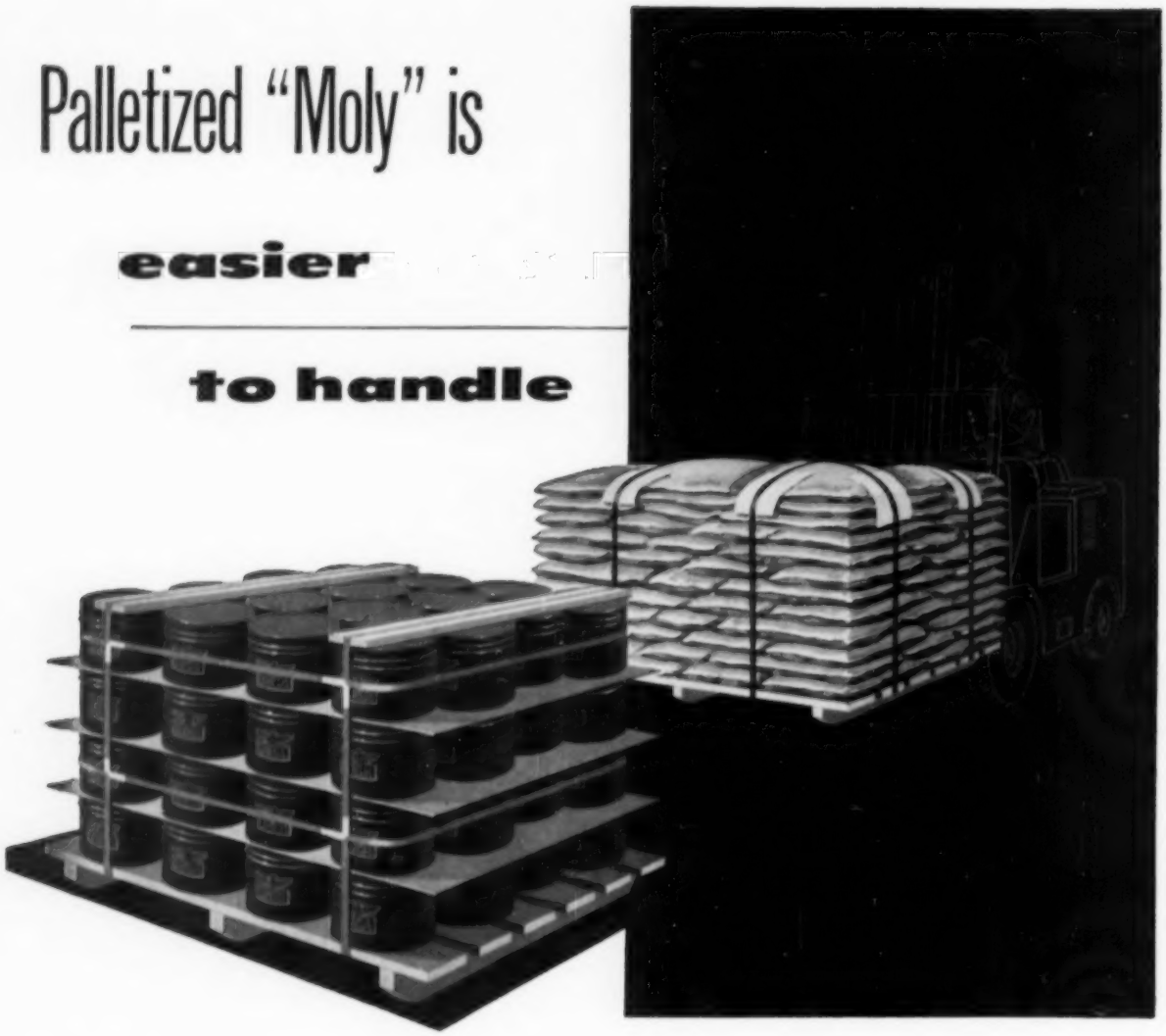
Palletized "Moly" is

easier

to handle



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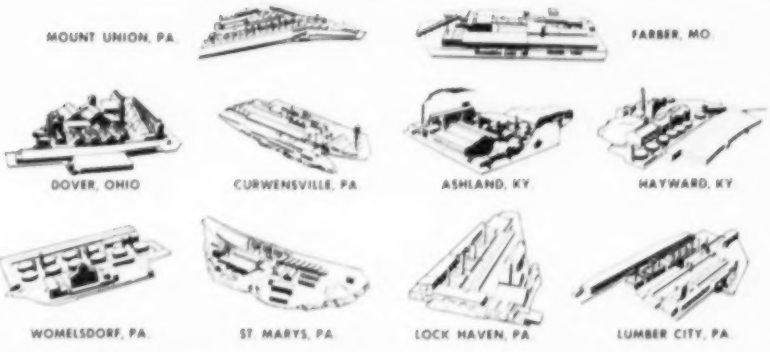

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NORTH AMERICAN REFRACTORIES LTD., 191 Victoria Ave., South, Hamilton, Ontario

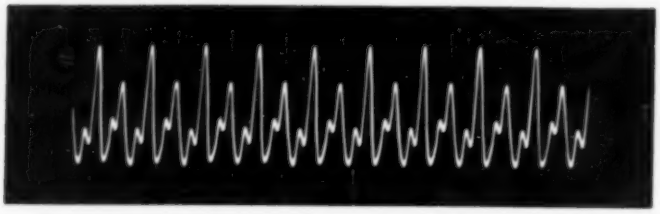
An intrstng exprmnt in spch

Some day your voice may travel by a sort of electronic "shorthand" when you telephone. Bell Laboratories scientists are experimenting with a technique in which a sample is snipped off a speech sound—just enough to identify it—and sent by wire to a receiver which rebuilds the original sound. Thus voices can be sent by means of fewer signals. More voices may economically share the wires.

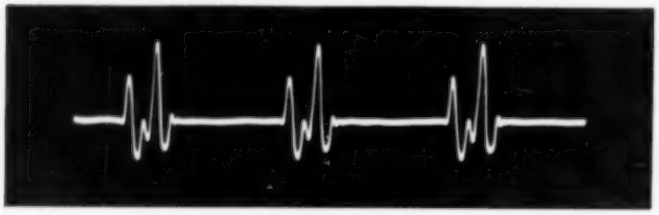
This is but one of many transmission techniques that Laboratories scientists are exploring in their search for ways to make Bell System wire and radio channels serve you more efficiently. It is another example of the Bell Telephone Laboratories research that keeps your telephone the most advanced on earth. *The oscilloscope traces at right show how the shorthand technique works.*

BELL TELEPHONE
LABORATORIES

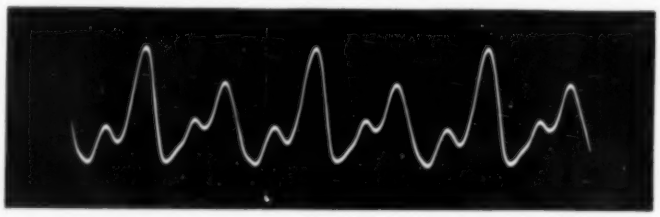
World center of communications research
Largest industrial laboratory in the United States



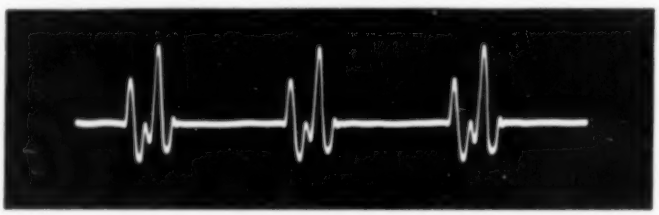
Vibrations of the sound "or" in the word "four." Pattern represents nine of the "pitch periods" which originate in puffs of air from the larynx when a word is spoken.



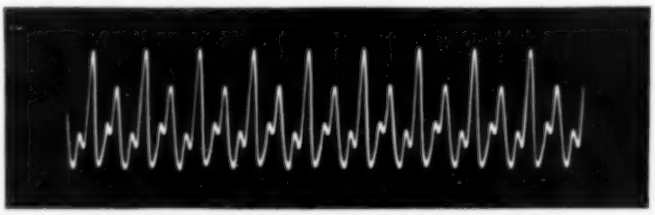
An electronic sampling of the "or" sound. One "pitch period" in three has been selected for transmission. This permits great naturalness when voice is rebuilt. Intelligible speech could be sent through a 1 in 6 sampling.



The selected samples are "stretched" for transmission. They travel in a narrower frequency band than complete sound.

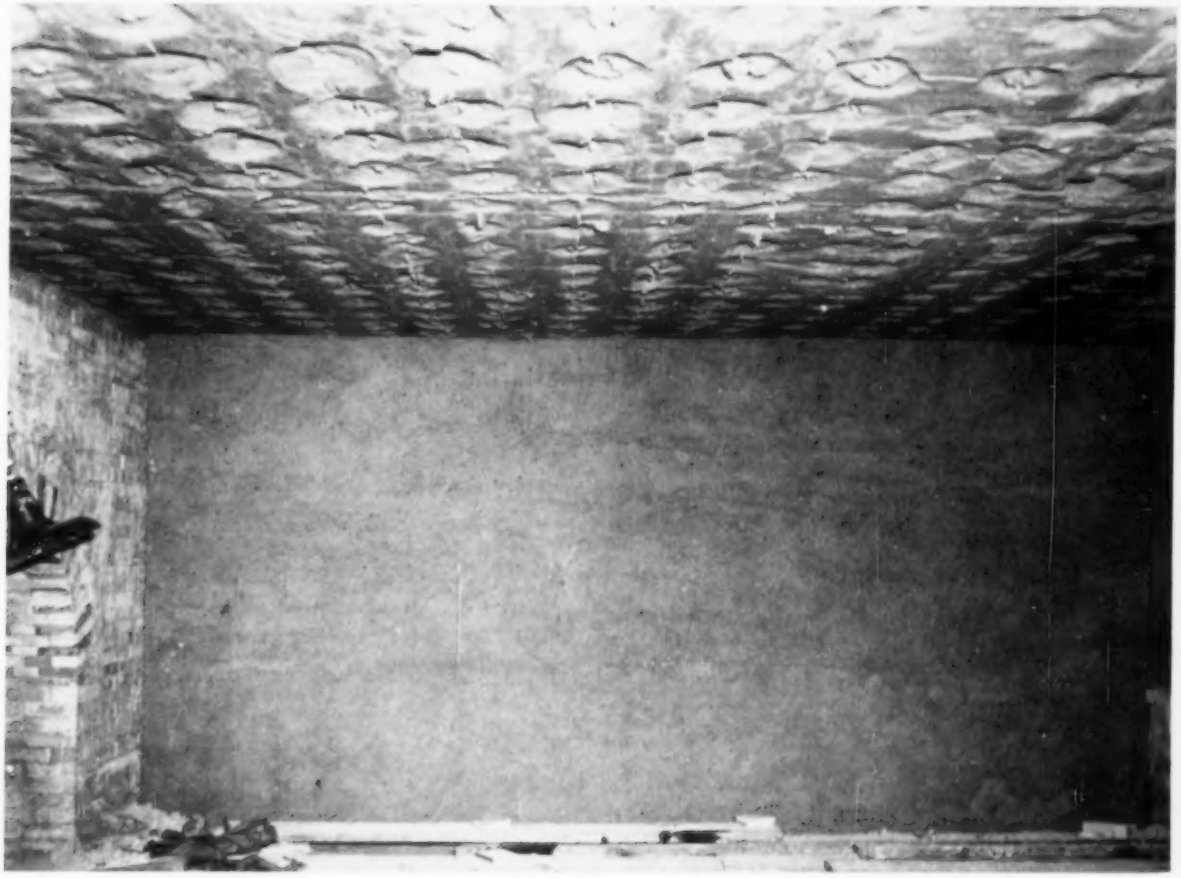


Using the stretched sample as a model, the receiver restores original frequency. In all speech, sounds are intoned much longer than is needed for recognition—even by the human ear. Electronic machines perform recognition far faster than the ear.



The receiver fills in gaps between samples, recreating total original sound. Under new system, three or four voices could travel at once over a pair of wires which now carries only one—and come out clearly at the end!

IMPROVE OPEN HEARTH PERFORMANCE



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Ramtite enclosures have increased air preheat temperatures from 200° to 300° F., reduced total heat time with a corresponding increase in production and a perceptible reduction in fuel consumption.

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Please send the items checked:

- ☐ Bulletin on Castable and Gunning Refractories
- ☐ Steel Plant Bulletin

Company Name .....
Attn: Mr. ..... Title .....
Address .....
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This is another in a series of advertisements depicting ways Ramtite Refractories serve the steel industry.

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CHICAGO CONCRETE ON THE JOB IN HOURS

500 TONS OF METAL BLASTED FROM SCALE PIT

What do you do when a mixer accidentally pours 500 tons of molten metal into the scale pit of an open hearth shop, putting the mixer completely out of production?

At 3.00 P.M. on a Wednesday in April, 1953 that question was put to CHICAGO CONCRETE. Although the job was over 2,000 miles away, a representative was on the scene appraising the damage in a matter of hours. Simultaneously he ordered out the manpower and equipment necessary to repair the damage while setting to work available manpower in cleaning up. Then . . . coupling the experience bred of 35 years of operation with the judicious use of dynamite, CHICAGO CONCRETE went to work. WITHIN DAYS THE ENTIRE MASS WAS REMOVED AND THE MIXER READY TO RETURN TO ITS JOB.

PRODUCTION TIME SAVED . . . 35 DAYS

By tried-and-proven-safe methods, CHICAGO CONCRETE removed that 500 tons of metal from the scale pit—taking care to safeguard the mixer itself throughout the entire operation. The savings to this mill in "down-time" was literally tens of thousands of dollars. This is another of many emergencies handled by CHICAGO CONCRETE every day, every week . . . handled by experienced men employing the utmost speed. You, too, can depend on CHICAGO CONCRETE in ANY emergency

CHICAGO CONCRETE CONSTRUCTION

Regardless of the size of the job — from a minor masonry, steel or foundation repair, to a complete furnace rebuild, CHICAGO CONCRETE offers you the know-how and facilities to handle any job. CHICAGO CONCRETE CONSTRUCTION COMPANY offers a COMPLETE industrial construction service . . .

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12233 S. AVENUE "O", Chicago 33, Ill., BAyport 1-8400

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SERVING THE PRIMARY METALS AND OIL INDUSTRIES WITH KNOW HOW, EQUIPMENT AND MANPOWER FOR 35 YEARS

Blast Furnace, Coke Oven, and Raw Materials Committee and National Open Hearth Steel Committee Programs

The Netherland Plaza Hotel, Cincinnati, will be the scene of the 39th conference, held Apr. 9 through 11, 1956. Registration will be on the 3rd Floor Foyer, at 3 to 9 pm on Sunday, April 8; 8 am to 5 pm on Monday and Tuesday, April 9 and 10; and 8 am to 4 pm on Wednesday, April 11. Buses for the plant trip on Wednesday, April 11, will leave the Netherland Plaza at 9 am and return at 4 pm. On Monday and Tuesday, authors and session chairmen for each day's program will meet for breakfast at 8 am in Parlor I.

Blast Furnace, Coke Oven, and Raw Materials Conference

MONDAY, APRIL 9

9:30 am to 12:15 pm—Pavillon Caprice

SIZING AND SINTERING OF ORES SESSION

Chairmen:

Douglas Joyce, General Superintendent, Algoma Steel Corp., Ltd., Sault Ste. Marie, Ont., Canada

Kurt Neustaetter, Assistant Superintendent, Plant 3 Blast Furnace, Inland Steel Co., East Chicago, Ind.

1. **Welcoming Remarks:**
   W. E. Marshall, Research Metallurgist, Armco Steel Corp., Middletown, Ohio and General Chairman, Blast Furnace, Coke Oven, and Raw Materials Committee, AIME.
2. **Design and Operation of No. 3 Sinter Strand at Jones and Laughlin's Benson Mines:**
   R. G. Fleck, Manager, and F. M. Hamilton, Metallurgical Engineer, Benson Mines, Jones and Laughlin Steel Corp., Star Lake, New York. (Preprinted)
3. **The Lurgi Sintering Plant of The Steel Company of Canada:**
   T. W. W. Trumper, General Foreman, Docks and Sintering, The Steel Co. of Canada, Ltd., Hamilton, Ont., Canada. (Preprinted)
4. **Ore Preparation Plant of Steel Company of Wales, Limited:**
   K. C. Sharp, Superintendent, Blast Furnaces, and H. R. Tufnail, Manager, Ore Preparation Plant, Steel Co. of Wales, Ltd., Port Talbot, South Wales. (Preprinted)
5. **Weirton's New Eight-Foot Wide Iron Ore Sintering Plant:**
   J. H. Strassburger, Assistant Vice-President, Engineering, National Steel Corp., Pittsburgh, Pa. (Preprinted)

12:30 pm—Parlor I

BLAST FURNACE, COKE OVEN, AND RAW MATERIALS EXECUTIVE BOARD LUNCHEON

2:00 to 5:00 pm—Pavillon Caprice

BLAST FURNACE OPERATIONS SESSION

Chairmen:

W. F. Huntley, Director, Blast Furnace Operation, Jones and Laughlin Steel Corp., Pittsburgh, Pa.

E. K. Miller, Jr., Assistant Superintendent, Blast Furnace Div., Gary Works, U. S. Steel Corp., Gary, Ind.

1. **Operating Experiences With High Beneficiated Burdens:**
   Douglas Joyce, General Superintendent, W. P. Dowhaniuk, Superintendent Blast Furnaces, and B. Marsden, Assistant Superintendent Blast Furnaces, Algoma Steel Corp. Ltd., Sault Ste. Marie, Ont., Canada. (Preprinted)
2. **New High-Grade Iron Ores and Agglomerates and Their Effect on Coke Rates:**
   John Griffen, Coal and Coke Consultant, Pittsburgh, Pa. (Preprinted)
3. **Burdening a Blast Furnace for Minimum Costs:**
   D. R. Bailey, Plant Metallurgist, Pittsburgh Steel Co., Monessen, Pa. (Preprinted)
4. **A Comparison of Blast Furnace Penetration With Model Studies:**
   J. B. Wagstaff, Physicist, U. S. Steel Corp., Kearny, New Jersey, and W. H. Holman, Assistant Manager, Steubenville Works, Wheeling Steel Corp., Steubenville, Ohio. (Preprinted)

LUNCHEON

Tuesday, April 10

12:30 pm—Parlors A, B, C, D

Annual Luncheon and Business Meeting, Blast Furnace, Coke Oven, and Raw Materials Committee

W. E. Marshall, Chairman

Everyone attending the Blast Furnace, Coke Oven, and Raw Materials session is invited to attend this luncheon and annual business meeting.

(Tickets $3.50, tips and tax included.)

TUESDAY, APRIL 10

9:30 am to 12:15 pm—Hall of Mirrors

JOINT SESSION
DESULPHURIZATION OF HOT METAL

Chairmen:

E. C. Sorrells, Division Superintendent, Steel Producing Div., Gary Works, U. S. Steel Corp., Gary, Ind.

W. H. Holman, Assistant Manager, Steubenville Works, Wheeling Steel Corp., Steubenville, Ohio.

1. **Application of Theoretical Principles of Desulphurization to Iron and Steelmaking:**
   J. F. Elliott, Associate Professor, and John Chipman, Professor, Department of Metallurgy, Massachusetts Institute of Technology, Cambridge, Mass.
2. **Use of Cyanamid in Hot Metal Ladles:**
   G. G. Hatch, Director, Research and Development, Quebec Iron and Titanium Corp., Sorel, Que., Canada.
3. **The Desulphurization of Molten Iron:**
   J. N. Hornak, Assistant Director, Steel Processing, Applied Research Laboratory, Fairless Works, U. S. Steel Corp., Monroeville, Pa., and E. J. Whittenberger, Chief Development Metallurgist, South Works, U. S. Steel Corp., Chicago, Ill. (Preprinted)
4. **Carbide Desulphurization:**
   D. E. Watkins, General Superintendent, Blast Furnaces and Coke Ovens, U. S. Pipe and Foundry Co., Birmingham, Ala., and J. R. McFarland, Supervisor, Technical Sales Department, Air Reduction Sales Co., Birmingham, Ala. (Preprinted)

9:30 am to 12:15 pm—North Hall

COAL AND COKE SESSION

Chairmen:

F. P. MacNaughton, Manager, Blast Furnaces and Coke Ovens, Ford Motor Co., Dearborn, Mich.

J. D. Doherty, Consulting Engineer, Island Creek Coal Sales Co., Huntington, W. Va.

1. **Pilot Scale Coke Ovens—Development and Operation:**
   John Mitchell, Director of Research, and R. T. Eddinger, Research Chemical Engineer, Eastern Gas and Fuel Associates, Boston, Mass. (Preprinted.)
2. **A New Pressure-Recording Eighteen-Inch Test Oven:**
   R. P. Aikman, Engineer, Research Department, Bethlehem Steel Co., Bethlehem, Pa.
3. **A Study of Pressure Relationships in Commercial Ovens:**
   D. C. Coleman, Superintendent Coke and Coal Chemical Works, and P. J. Farley, Research Chemist, Fairless Works, U. S. Steel Corp., Morrisville, Pa. (Preprinted)
4. **Low Fuel Rates Obtained With Three-Foot Blast Furnace Using Prepared Ores and Coke-Anthracite Mixtures:**
   R. C. Buehl, Chief, Ferrous Pyrometallurgy Section, and M. B. Royer, Supervising Extractive Metallurgist, U. S. Bureau of Mines, Pittsburgh, Pa. (Preprinted)

2:00 to 5:00 pm—Pavilion Caprice

ORE MINING AND DOCK OPERATIONS SESSION

Chairman:

James Chisholm, Assistant Superintendent, Blast Furnaces, Fairless Works, U. S. Steel Corp., Morrisville, Pa.

1. **Fairless Works Dock Operations:**
   Movies presented by R. H. White, Blast Furnace Superintendent, Fairless Works, U. S. Steel Corp., Morrisville, Pa.
2. **Underground Mining:**
   J. S. Westwater, Mine Superintendent, Cleveland-Cliffs Iron Co., Ishpeming, Mich.
3. **Iron Ore Unlimited:**
   Movies presented by W. N. Matheson, Vice-President, Oliver Iron Mining Div., U. S. Steel Corp., Duluth, Minn.

2:00 to 5:00 pm—North Hall

RESEARCH AND DEVELOPMENT ON SINTERING SESSION

Chairmen:

J. B. Wagstaff, Physicist, U. S. Steel Corp., Kearny, New Jersey.

Michael Tenenbaum, Assistant Superintendent, Quality Control Department, Inland Steel Co., East Chicago, Ind.

1. **Reaction Zones in the Iron Ore Sintering Process:**
   R. D. Burlingame, Weirton Steel Co. Fellow, Gust Bitsianes, Associate Professor of Metallurgy, and T. L. Joseph, Professor of Metallurgy, University of Minnesota, Minneapolis, Minn. (Preprinted)
2. **Methods of Pilot-Scale Experiments in Sintering:**
   T. L. Myron, C. J. Davis, and R. J. Franklin, Applied Research Laboratory, Fairless Works, U. S. Steel Corp., Monroeville, Pa.
3. **Methods for Increasing the Production Rate of Flue Dust Sinter:**
   E. C. Rudolphy, General Supervisor, Metals Research, and E. J. Whittenberger, Chief Development Metallurgist, South Works, U. S. Steel Corp., Chicago, Ill. (Preprinted)
4. **Sintering Iron Ores and Concentrates at Extaca:**
   R. L. Bennett, Supervisor, Field Development, R. E. Hagen, Development Engineer, and M. V. Mielke, Superintendent, Extaca Plant, Oliver Iron Mining Div., U. S. Steel Corp., Duluth, Minn. (Preprinted)

ANNUAL FELLOWSHIP DINNER

Tuesday, April 10

6:30 pm—South Hall

Reception and Cocktail Party for dinner guests

7:00 pm—Hall of Mirrors

Annual Fellowship Dinner

Toastmaster: J. S. Marsh, Assistant Manager of Research
Bethlehem Steel Co., Bethlehem, Pa.

Speaker: Thomas R. Reid, Director of Civic Affairs
Ford Motor Co., Dearborn, Mich.
"You and the Hoover Commission Report"

National Open Hearth Steel Conference

MONDAY, APRIL 9

10:00 to 10:30 am—Hall of Mirrors

GENERAL SESSION

1. **Welcoming Remarks:**
   H. G. Grim, Vice-President, Heppenstall Co., Pittsburgh, Pa., and General Chairman, National Open Hearth Steel Committee, AIME.
2. **Announcements and Reports**

10:30 am to 12:15 pm—Hall of Mirrors

BASIC OPERATIONS SESSION

Chairmen:
G. H. Todd, Assistant General Superintendent, Armco Steel Corp., Ashland, Ky.
T. D. Hess, Superintendent No. 1 Open Hearth, Youngstown Sheet & Tube Co., East Chicago, Ind.

1. **Observations on European Operations:**
   L. R. Berner, Superintendent of Steel Production, Inland Steel Co., East Chicago, Ind.
2. **Statistical Quality Control Methods in Open Hearth Steelmaking:**
   a) *A Quality Incentive for Open Hearth Melters:*
      J. R. Behrman, Staff Assistant, Alan Wood Steel Co., Conshohocken, Pa.
   b) *Statistical Quality Control Methods in Open Hearth Production and Their Effect on Tonnage:*
      A. V. Lang, Open Hearth, Youngstown Sheet and Tube Co., Youngstown, Ohio.
3. **Physical Characteristics and Chemical Analysis of Foreign Charge Ores and Their Effect on Open Hearth Production:**
   W. E. Brandt, Assistant Division Superintendent, Steel Production, U. S. Steel Corp., Homestead, Pa.
4. **Carbon Removal With Roof Mounted Oxygen Jets in Open Hearth Furnaces:**
   J. E. Hood, Assistant Superintendent of Open Hearths, The Steel Co. of Canada, Ltd., Hamilton, Ont., Canada.

10:30 am to 12:15 pm—North Hall

ACID OPERATIONS SESSION

Chairmen:
John Dugan, Manager and Chief Metallurgist, Roll Div., Ohio Steel Foundry Co., Lima, Ohio
Earl Vance, General Superintendent, Continental Foundry and Machine Div., Blaw-Knox Co., Wheeling, W. Va.

1. **Use of Natural Gas to Atomize Heavy Oil in the Acid Open Hearth:**
   R. J. Sherlock, Assistant Works Manager, Union Steel Castings Div., Blaw-Knox Co., Pittsburgh, Pa.
2. **An Evaluation of Hydrogen Sampling Techniques for Liquid Steel:**
   J. G. Bassett, Research Engineer, J. W. Dougherty, Research Engineer, and G. R. Fitterer, Director of Research, Acid Open Hearth Research Association, Inc., Pittsburgh, Pa.

12:30 pm—Room J

PHYSICAL CHEMISTRY OF STEELMAKING LUNCHEON

2:00 to 5:00 pm—Hall of Mirrors

OPERATING METALLURGY SESSION

Chairmen:
D. C. Hilty, Research Metallurgist, Electro Metallurgical Co., Niagara Falls, N. Y.
R. D. Hindson, Assistant Chief Metallurgist, The Steel Co. of Canada, Ltd., Hamilton, Ont., Canada

1. **Report on European Trip:**
   C. R. Taylor, Supervising Metallurgist, Armco Steel Corp., Middletown, Ohio.
2. **Steels With Low Hydrogen Contents:**
   a) *Why Low Hydrogen Contents are Desirable in Steel:*
      E. R. Slaughter, Principal Metallurgist, Battelle Memorial Institute, Columbus, Ohio.
   b) *Effect of Melting Practice on Hydrogen Content of Steel:*
      Henry Epstein, Research Engineer, Bethlehem Steel Co., Bethlehem, Pa.
   c) *Methods and Effects of Vacuum Casting Steel:*
      L. R. Cooper, Assistant Metallurgical Engineer, Heppenstall Co., Pittsburgh, Pa.
3. **Influence of Ingot Thickness on Deep-Drawing Steels:**
   a) *Ingot Thickness and Its Effects on Drawing Quality:*
      J. S. McNairn, Supervisor Quality Control, Steel Div., Ford Motor Co., Dearborn, Mich.
   b) *Effect of Ingot Thickness on the Quality of Rimmed Steel:*
      W. H. Mayo, Metallurgical Engineer, Process Control, U. S. Steel Corp., Pittsburgh, Pa.

Prepared discussion by C. F. Schrader, Assistant Superintendent, Quality Control, Inland Steel Co., East Chicago, Ind.

2:00 to 5:00 pm—North Hall

REFRACTORIES AND MASONRY SESSION

Chairmen:
M. P. Fedock, Ceramic Engineer, Republic Steel Corp., Canton, Ohio.
Martin Theil, Superintendent of Masonry, U. S. Steel Corp., Youngstown, Ohio.

1. **General Use of Basic Refractories in European Open Hearth Practice:**
   A. H. Sommer, Vice-President and General Superintendent, Keystone Steel and Wire Co., Peoria, Ill.
2. **Progress on Use of Basic Brick Checkers:**
   Lead-off paper by C. G. Benton, Superintendent, Open Hearth and Bessemer, Algoma Steel Corp., Ltd., Sault Ste. Marie, Ont., Canada.
   A. H. Sommer, Vice-President and General Superintendent, Keystone Steel and Wire Co., Peoria, Ill.
3. **Practices Affecting Refractories Performance:**
   a) *Relationship of Furnace Dimensions and Firing Rates on Furnace and Roof Performance:*
      W. S. Debenham, Research Associate, U. S. Steel Corp., Pittsburgh, Pa.
   b) *A Study of the Factors Affecting Temperature Distribution in Open Hearth Roofs:*
      J. H. Richards, Research Associate, Applied Research Laboratory, U. S. Steel Corp., Monroeville, Pa.

4. **Special Roof Brick Trials—Open Discussion:**
B. L. Dorsey, Refractories Engineer, Jones and Laughlin Steel Corp., Pittsburgh, Pa., and others.

5. **Bottom Construction and Maintenance:**
a) Lead-off paper by H. M. Kraner, Ceramic Engineer, Bethlehem Steel Co., Bethlehem, Pa.
G. A. Ferris, Open Hearth Superintendent, Ford Motor Co., Dearborn, Mich.
b) *Gun Placing Tapholes:*
A. M. Kroner, Assistant Superintendent No. 3 Open Hearth, Inland Steel Co., East Chicago, Ind.

6:00 pm—Parlor G

NATIONAL OPEN HEARTH STEEL EXECUTIVE BOARD

TUESDAY, APRIL 10

9:30 am to 12:15 pm—Pavillon Caprice

COLD METAL AND BASIC FOUNDRY PRACTICE SESSION

Chairmen:
H. L. Tear, Superintendent, Open Hearth, Washburn Wire Co., Phillipsdale, R. I.
D. J. Murphy, Open Hearth Superintendent, Scullin Steel Co., St. Louis, Mo.

1. **Desulphurization of Cupola Metal for Use in Open Hearth:**
William Webb, Metallurgist, Central Div., Barium Steel Corp., Harrisburg, Pa.

2. **Optimum Operating Conditions and Design for Maximum Roof Life:**
L. D. Yager, Open Hearth Superintendent, Laclede Steel Co., Alton, Ill.
J. L. Jennings, Open Hearth Superintendent, General Steel Castings Corp., Granite City, Ill.

3. **Economics of Use of Pig Iron in Cold Metal Heats:**
G. J. Schwartz, Superintendent, Melted Metal Department, American Steel Foundries, Alliance, Ohio.
C. H. Alexander, Assistant Open Hearth Superintendent, Lukens Steel Co., Coatesville, Pa.

4. **Use of Electronic Direct Reading Analyzers in Steelmaking:**
K. P. Campbell, Works Metallurgist, Sheffield Steel Corp., Houston, Texas.

5. **Effective Ladle Deoxidation on Steel Cleanliness:**
C. R. Funk, Metallurgist, American Locomotive Co., Latrobe, Pa.

9:30 am to 12:15 pm—Hall of Mirrors

JOINT SESSION
DESULPHURIZATION OF HOT METAL

Chairmen:
E. C. Sorrells, Division Superintendent, Steel Producing Div., Gary Works, U. S. Steel Corp., Gary, Ind.
W. H. Holman, Assistant Manager, Steubenville Works, Wheeling Steel Corp., Steubenville, Ohio

1. **Application of Theoretical Principles of Desulphurization to Iron and Steelmaking:**
J. F. Elliott, Associate Professor, and John Chipman, Professor, Department of Metallurgy, Massachusetts Institute of Technology, Cambridge, Mass.

2. **Use of Cyanamid in Hot Metal Ladles:**
G. G. Hatch, Director, Research and Development, Quebec Iron and Titanium Corp., Sorel, Que., Canada.

3. **The Desulphurization of Molten Iron:**
J. N. Hornak, Assistant Director, Steel Processing, Applied Research Laboratory, Fairless Works, U. S. Steel Corp., Monroeville, Pa., and E. J. Whittenberger, Chief Development Metallurgist, South Works, U. S. Steel Corp., Chicago, Ill.

4. **Carbide Desulphurization:**
D. E. Watkins, General Superintendent, Blast Furnaces and Coke Ovens, U. S. Pipe and Foundry Co., Birmingham, Ala., and J. R. McFarland, Supervisor, Technical Sales Department, Air Reduction Sales Co., Birmingham, Ala.

2:00 to 5:00 pm—Hall of Mirrors

OPERATING AND COMBUSTION SESSION

Chairmen:
F. C. McGough, Superintendent of Maintenance and Construction, Detroit Steel Corp., Portsmouth, Ohio.
H. V. Flagg, Combustion Engineer, Armco Steel Corp., Middletown, Ohio.

1. **Combustion of Liquid Fuel in the Open Hearth Furnace:**
H. V. Flagg, Combustion Engineer, Armco Steel Corp., Middletown, Ohio.

2. **Open Hearth Continuous Waste Gas Analysis and Control:**
F. S. Swaney, Combustion Engineer, Jones and Laughlin Steel Corp., Pittsburgh, Pa.

3. **Methods of Use and Benefits Derived from Automatic Reversal:**
L. R. Berner, Superintendent of Steel Production, Inland Steel Co., East Chicago, Ind.

4. **Automatic Steam—Fuel Control Ratio:**
W. H. Kahl, Combustion Engineer, Inland Steel Co., East Chicago, Ind.

5. **Dual Open Hearth Roof Temperature Control Performance and Maintenance:**
R. A. Lambert, Superintendent Steam Efficiency and Combustion, Jones and Laughlin Steel Corp., Pittsburgh, Pa.

ANNUAL FELLOWSHIP DINNER

Tuesday, April 10

6:30 pm—South Hall

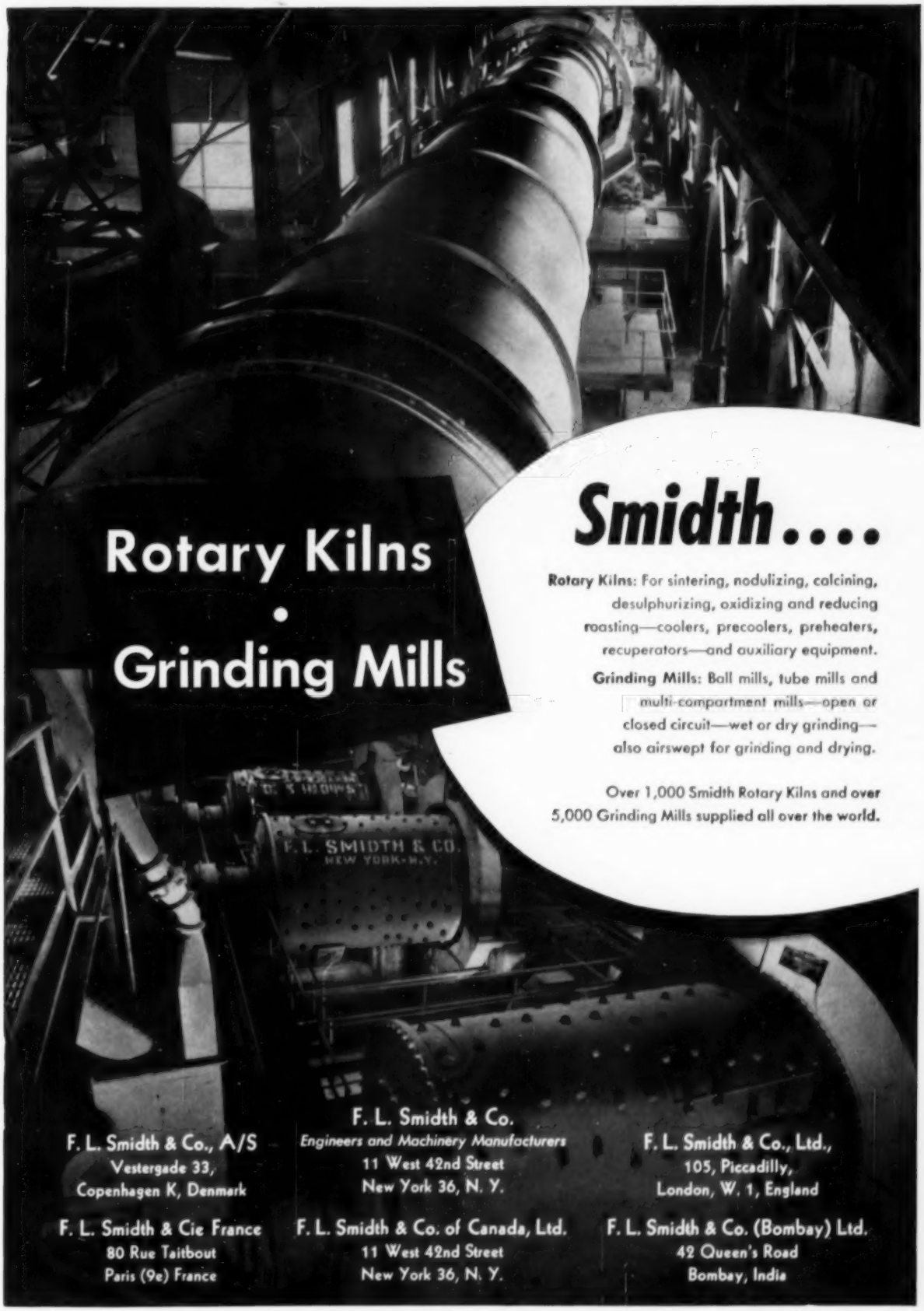
Reception and Cocktail Party for dinner guests

7:00 pm—Hall of Mirrors

Annual Fellowship Dinner

Toastmaster: J. S. Marsh, Assistant Manager of Research
Bethlehem Steel Co., Bethlehem, Pa.

Speaker: Thomas R. Reid, Director of Civic Affairs
Ford Motor Co., Dearborn, Mich.
"You and the Hoover Commission Report"



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Carbon Removal with Roof Mounted Oxygen Jets in Open Hearth Furnaces

by J. E. Hood

OXYGEN for decarburization, introduced by means of a water-cooled lance through the roof of the furnace, was developed by the Steel Co. of Wales, which holds the patent for the process. The Steel Co. of Canada has tried the more conventional systems of using oxygen introduced into the bath by a 1 in. diam pipe either through the back wall or through the wicket hole of the middle door, but each time discarded its use because of interference with other furnaces in the shop. The process patented by the Steel Co. of Wales could be adopted successfully in the No. 3 open hearth shop without any interference; so for this reason it was decided to install a unit on the No. 34 furnace and assess its value.

The lance was used for two furnace roof campaigns; the first campaign was to establish a satisfactory pattern for using the oxygen, and the second was to assess its value when compared to the normal practice. To get what was felt to be a fair comparison, oxygen was used on alternate heats, and the heats where oxygen was used were compared against the heats where oxygen was not used.

Equipment Used

The tests were run on the No. 34 furnace, a 250-ton unit having 1000 sq ft of hearth area and tapping 295 tons at the time of these tests. It is of basic end construction with main and port roofs of silica brick.

The oxygen lance and mountings were constructed and erected, with slight modifications, according to the specifications of the Steel Co. of Wales. Essentially the unit consisted of a 1 in. diam pipe having a water-cooled jacket. It was lowered to a desired level above the bath through a hole in the furnace roof. The unit was mounted just back of the crown of the roof over the middle door in order to clear all crane movement over the furnace. Controls for operating the lance and regulating and recording oxygen flow were mounted on the furnace console.

Conditions for Evaluation of the Oxygen Lance

As previously mentioned, the first roof campaign was run using the oxygen lance to establish a satisfactory basis for the test comparison, and to iron out any difficulties with the auxiliary equipment. From the results of this campaign the following test pattern was evolved:

1) Oxygen heats were to be melted from 0.70 to 1.00 pct carbon to allow for proper sulfur removal. Oxygen use was to start at 0.40 pct carbon.

2) Non-oxygen heats were to be melted between 0.40 and 0.70 pct carbon.

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3) Both types of heats were to be worked as fast as possible, subject to considerations of working and tapping temperatures required, proper slag conditions, and roof temperature.

4) During the oxygen blow the furnace was to be on normal stack operating pressures, and with fan air equivalent of 80 million Btu's per hr approx.

5) Prior to the oxygen blow, the furnace roof was to be cooled off for 3 to 5 min.

6) Oxygen rate was to be at a maximum figure without splashing the roof seriously, increasing as conditions allowed.

Method of Working Heats

The charge oxide, sinter in this case, was adjusted for alternate heats to achieve the desired melt carbon. The furnace was worked hot, and in both cases the furnace helpers started making lime additions on completion of the flush period in order to achieve a CaO/SiO_2 ratio at melt between 2.7/1 and 3.0/1.

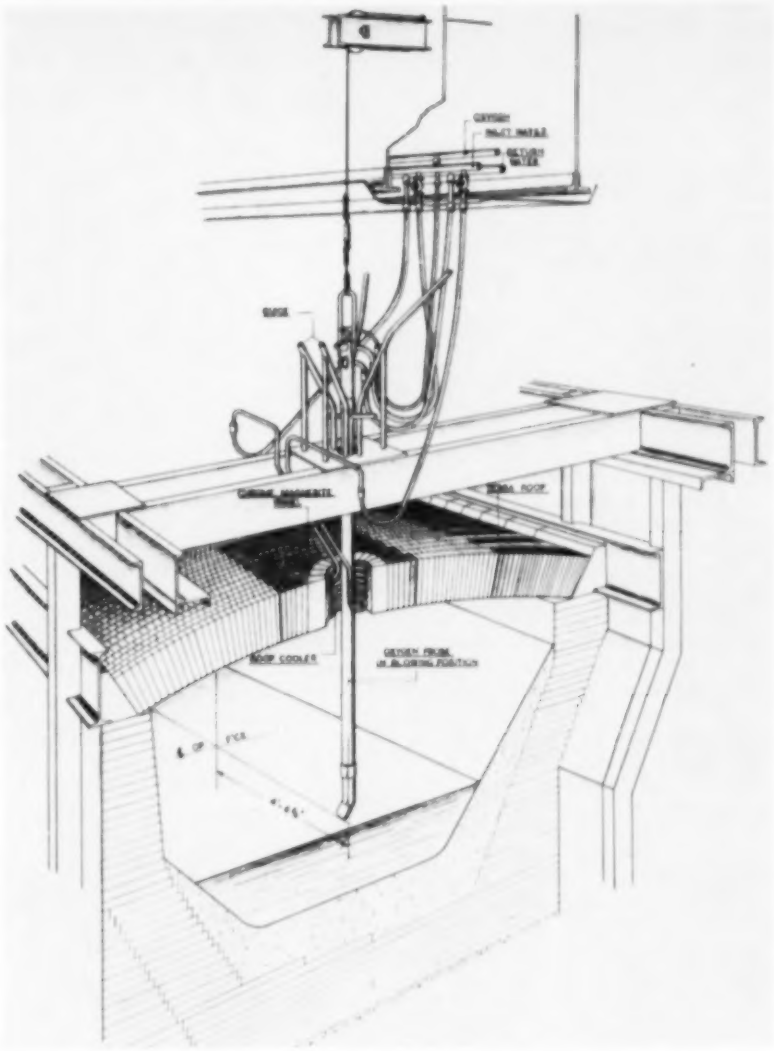
In the case of those heats using oxygen, sufficient lime was added with the ore to build the slag ratio to a minimum of 3.0/1 by the time 0.40 carbon was reached. Just prior to 0.40 carbon, final lime and ore additions were made to the furnace, the furnace controls set, the oxygen lance was lowered to within 4 to 6 in. of the bath, and the oxygen was turned on. Oxygen flow was gradually increased until maximum flow was achieved at about 0.20 carbon. A test for phosphorus, sulfur and manganese was run at 0.20 to 0.25 carbon, and the heat was tapped when the desired carbon level was reached. Bath temperatures were taken frequently enough so the melters could judge whether or not fuel was to be put on the furnace during the blowing period. This

Table I. Oxygen and Non-Oxygen Heats in 250-Ton Open Hearth Furnace

	Total CaO Lb Charged	Pct Hot Metal	Pct Yield	Btu/ Ton	100 Cu Ft O₂/ Ton	Pct Carbon		Pct Sulfur	
						Melt	Ladle	Melt	Ladle
Oxygen	34,948	48.61	86.47	3,464	1,536	0.92	0.057	0.041	0.030
Non-Oxygen	34,466	48.05	86.16	3,851	—	0.81	0.072	0.041	0.030

Table II. Operating Time on Heats in 250-Ton Open Hearth Furnace

	Melt Time, Hr.	Working Time, Hr.	C-T Time, Hr.	Interval T-C, Hr.	Tap-Tap Time, Hr.	Tons/ Hr. Tap-Tap	Tons/ Heat
Oxygen	5:49	1:59	7:48	1:18	9:06	32:90	296.5
Non-Oxygen	6:02	2:07	8:09	1:42	9:51	30:63	297.0



Using a slight modification of the technique developed and patented by the Steel Co. of Wales, the Steel Co. of Canada conducted successful decarburization experiments with an oxygen jet through the open hearth roof. The drawing, after A. J. Kesterton, shows the oxygen lance in a furnace at the Abbey Works of the Steel Co. of Wales. (A paper on the work in South Wales will be published in a future issue of Journal of Metals.)

was done in only a few instances. Normally fuel was restored on the completion of the blow after the lance had been retracted.

In the case of those heats not using oxygen, melting between 0.40 and 0.70 carbon was tried. Similar to the oxygen heats, lime additions were commenced shortly after the completion of the flushing period to achieve a melt CaO/SiO_2 ratio between 2.7/1 and 3.0/1. From the melt time the heats were worked with ore and lime as fast as bath conditions would permit, with the final ore addition being made at 0.15 to 0.20 carbon. Sufficient lime was added during the working period to tap these heats with a minimum CaO/SiO_2 ratio of 3.0/1.

Results

Following the predescribed methods for working both groups of heats results were obtained, based on 55 heats using oxygen and 56 heats made without oxygen.

This total of 111 heats comprised all the heats on the roof campaign, excepting those heats made immediately following the roof repair or other brick repairs until the furnace was in normal operating condition, and excepting a few heats which for both oxygen and non-oxygen had definite abnormalities attributable to neither process, and which would have caused a definite distortion of the comparison. The total number of heats on the roof campaign was 130, the furnace being taken off for rebuilding at that time.

For both groups of heats Table I compares total lime consumption, percentage of hot metal, yield, fuel consumption, oxygen flow, and carbon and sulfur at melt and in the ladle. The only significant differences, apart from the oxygen consumption itself, are the lower fuel consumption and lower average finish carbon for the oxygen heats.

Table II illustrates the pertinent operating data for both groups of heats. There is a 45 min saving in tap-to-tap time in favor of the oxygen heats, and it is worthy to note 24 min of this time was saved in the bottom interval. The increase in tons per hour was 2.27 in favor of the oxygen heats.

The Steel Co. of Canada is satisfied with the proficiency of this method of utilizing oxygen for decarburization, and on a shop basis, would use the same practice as was used on the test program.

Production-Scale Vacuum Steel Degassing

by A. Tix

IN the field of melting and casting of metals in vacuum for the purposes of degassing and purification excellent pioneer work was done between World War I and II by W. Rohn,[1] who carried out the melting and casting of steels and special alloys in low and medium frequency furnaces up to 5 tons in a vacuum of about 5 mm of mercury. After World War II, high vacuum melting furnaces with capacities between 25 kg and 1 ton operating at 10^{-4} mm of mercury were developed. These furnaces are primarily used for melting pure iron, copper alloys, and high temperature alloys.[2]

In 1935 it was established that a high hydrogen content is the cause of flaking during the cooling of forgings.[3] The steel industry endeavored, therefore, to reduce the hydrogen content of the molten steel by appropriate melting processes, drying of the additions, etc. The successes achieved by these means, however, did not furnish a sufficient guarantee that flakiness could be entirely eliminated from heavy forgings without a special heat treatment. It was obvious that an effort should be made to reduce the hydrogen content of the molten steel to the required minimum by vacuum degassing. But it has not been possible to construct the vacuum melting furnaces required for heavy forging ingots of up to 150 tons. It appeared more practical to dispense with melting in vacuum and simply to pour into the ladle and/or mold in vacuum. In 1950 experiments were, therefore, initiated at Bochumer Verein in Germany to determine whether this was feasible on a commercial scale. The following is a report on this work:

There are three methods of steel degassing:

1) Ladle degassing, in which the full tapping ladle is exposed to the vacuum.
2) Stream-droplet degassing, i.e., by pouring the contents of the tapping ladle into a second ladle in vacuum.

A. TIX is the works director and member of the Board of the Gussstahlwerk Bochumer Verein A.G., Bochum, Germany.

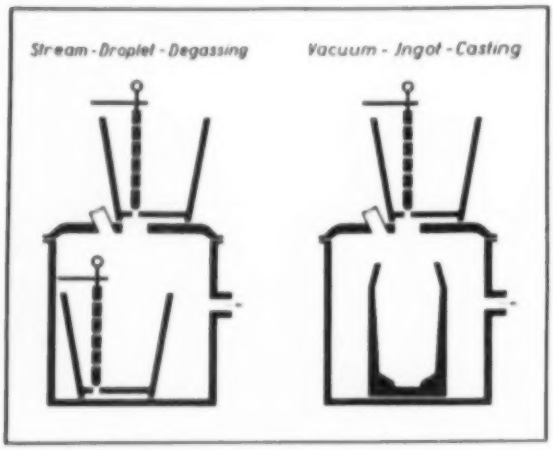


Fig. 1—Both stream-droplet and vacuum ingot casting techniques have proven successful in producing heavy forgings free from hydrogen flakes.

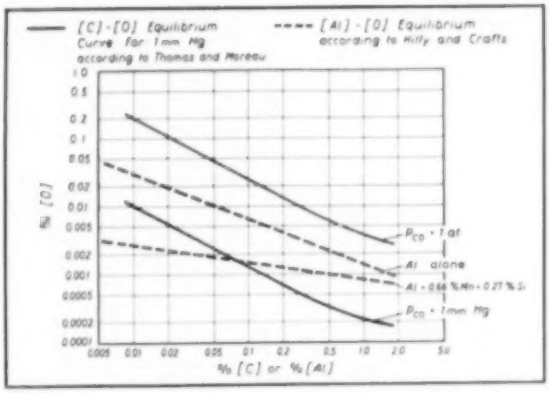

[C]-[O] Equilibrium Curve for 1 mm Hg according to Thomas and Moreau
[Al]-[O] Equilibrium according to Hilty and Crafts
% [O]
% [C] or % [Al]
P_{CO} = 1 at
Al alone
P_{CO} = 1 mm Hg

Fig. 2—The equilibrium diagram of carbon and aluminum with oxygen in iron at 1600°C shows that for steels of more than 0.1 pct C deoxidation occurs at pressures indicated.

3) Vacuum ingot casting, in which the ingot is cast in vacuum.

In the process of ladle degassing, the ladle filled with steel and slag is placed in the vacuum chamber, which is evacuated. Violent boiling and escape of gas from the steel results. When degassing is completed, the ladle is taken out of the vacuum chamber and the steel is cast in air as ingots or castings.

This method of ladle degassing has only a limited range of application, due to the ferrostatic pressure of the contents of the ladle.[4] Furthermore, the lower layers in the ladle cannot take part in the surface reactions unless the melt is stirred.

A diagram of the stream-droplet process is given in the left half of Fig. 1. The empty casting ladle is degassed in the vacuum chamber before filling. The air-tight tapping ladle is placed on top of the vacuum chamber, the entry to the chamber being sealed by a sheet of aluminum which fuses under the action of the molten steel. With a pouring rate of about 10 tons per min the pouring from one ladle into the other will result in a drop of temperature of 60°F. After the vacuum treatment, the contents of the second ladle is then cast in air.

In vacuum ingot casting (Fig. 1, right), there is an ingot mold inside the vacuum chamber. An intermediate ladle, such as is normally used for the casting of heavy ingots, is placed on top of the cover and vacuum-sealed. The tapping ladle can also be used without any intermediate ladle. If the drop of temperature can be disregarded, both of these processes can, in principle, be applied successively to the same melt. This has occasionally proved to be an advantage. As far as equipment possibilities are concerned, there is no limit to the size of the ingots to be cast. As soon as the mold is full normal atmospheric pressure is restored.

Preliminary experiments with a vacuum chamber for a 60-ton ladle using water-jet blowers proved the feasibility of the process. A combined pumping system was later erected by the firm of Leybold. Suitable drying filters with simple cleaning devices protect the pumping system from dust. The first plan was based on the assumption that the vacuum treat-

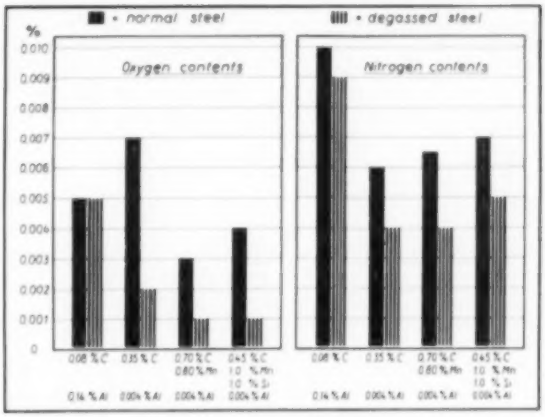


Fig. 3—Vacuum cast (or degassed) killed steels generally show considerably lower oxygen and nitrogen than air cast steels.

ment would yield a quantity of gas, which, at 1 atmo and room temperature, would be at least equivalent to the volume of the molten steel.

A number of advantages and special phenomena result from casting in vacuum:

One important advantage is the prevention of oxidation of the metal stream and of the steel surface. It is thus possible to dispense with the processes hitherto used in casting at normal atmospheric pressure, such as covering the hot top and the use of oxygen-repellent agents.[5] In addition, splashes on the mold wall are not dangerous as they do not oxidize.

As the killed, non-degassed steel enters the vacuum the metal stream is split up into tiny droplets. This dispersal and spinning of the metal droplets intensifies the degassing process. The behavior of the metal stream depends on the degree of the vacuum, on the shape of the nozzle, and on the gas content of the steel. Therefore, the operator is in a position to vary the casting conditions within very wide limits. While a spraying metal stream is undesirable in casting in air because of oxidation of the stream, this factor need not be considered in vacuum casting.

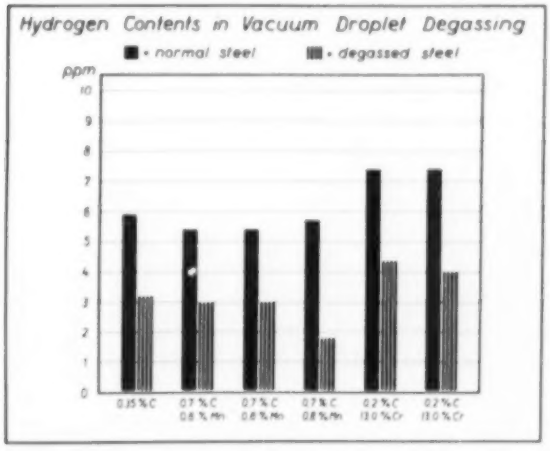
Experience has shown that when vacuum-casting an ingot it is advisable not to coat the mold. This eliminates the well-known danger that the steel may absorb hydrogen from the coating, which can increase the hydrogen content of molten steel up to 100 pct.[6] The uncoated molds used in vacuum ingot casting have a longer life than the coated molds used in open-air casting. It has also been revealed that in vacuum the escape of gas is particularly violent at the mold wall. It has the same repellent effect on nonmetallic particles as does the coating. Dross of this kind, however, occurs very rarely in vacuum ingot casting.

The vacuum treatment of ladle and/or mold is particularly important for the hot top which, in the case of big ingots, often contains considerable quantities of water. The ordinary drying with gas burners does not guarantee a complete extraction of the moisture, as drying tests in vacuum have shown.

The possibility of keeping the metal stream and the rising surface of the bath under observation offers a number of advantages in the casting process. By varying the pouring and vacuum conditions, for instance, the observing engineers are able to control the casting operation.

Since droplet dispersion exposes a very large surface of molten metal, effective degassing can be accomplished at relatively high pouring rates, and due to the lower gas content of the steel, a high casting speed may be maintained. Pouring rates may also be kept low without risking the occurrence of inclusions as the metal stream does not oxidize, and the oxygen content is thus greatly reduced by the degassing. But for heavy forging ingots the choice of the casting speed is limited by the fact that if casting is too slow, owing to the drop in the steel temperature, oxide inclusions do not rise easily and ingot imperfections may result. On the other hand, too rapid casting may cause excessive boiling of the steel at the mold walls, resulting in ingot cracks. It is noteworthy that the degassed steel possesses better flow properties than non-degassed steel.

The gases removed by the pumps in plant experiments contained considerable amounts of hydrogen, carbon monoxide and nitrogen. In a 25-ton ingot vacuum cast from chrome molybdenum steel, for instance, the following composition was established: 40 pct CO, 3.8 pct CO_2 23.0 pct H_2, 33.2 pct N_2. The effect of pressure of the carbon-oxygen equilibrium in unkilled molten steel is shown by the solid lines in Fig. 2.[7] The dotted lines indicate the deoxidation equilibrium with respect to aluminum.[8] The diagram



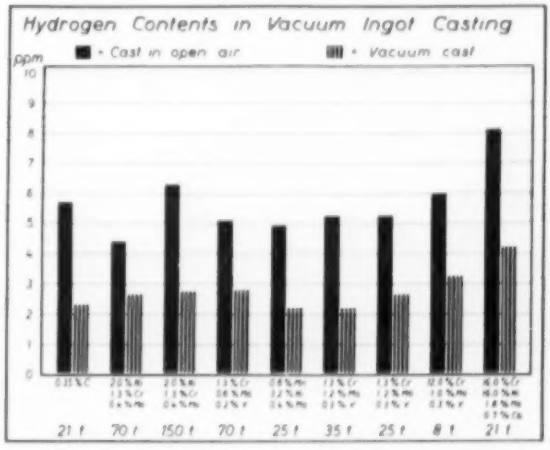


Fig. 4 (left) and Fig. 5 (right)—There is a significant reduction in the hydrogen content of molten steel after stream-droplet degassing (left) as well as steel cast in a vacuum (right).

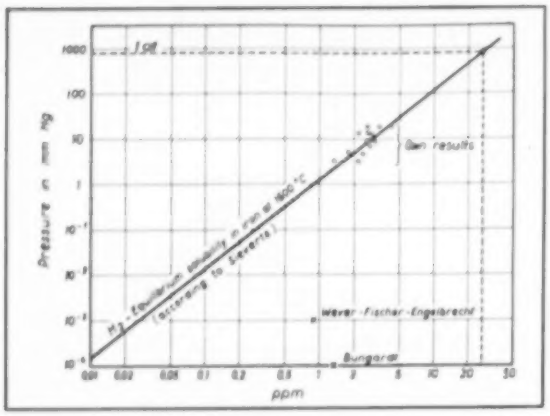


Fig. 6—Under equilibrium, which can be approached with vacuum techniques, hydrogen solubility decreases with the pressure square root.

shows that in the case of killed steels with carbon contents more than 0.1 pct a release of carbon monoxide, i.e., an additional deoxidation, occurs at the pressures involved here, if the aluminum concentration is not too high.

Apart from these equilibrium problems carbon monoxide can also arise from the reaction between the molten steel and solid oxides or ceramic masses. For this reason analyses for total oxygen of air-cast and vacuum-cast steels give clearer indications than analyses of pumped-off gases. Fig. 3 shows that considerable differences occur in the oxygen contents in killed steels with the exception of the aluminum-killed first steel. The nitrogen contents are also clearly shown to be lower in the vacuum treated steel (Fig. 3).

The determination of hydrogen in samples taken in molten condition showed very definite results. Use was made here of the sampling method developed at Krupp's and the tin-fusing process.[9] The liquid steel samples were taken from a ladle in front of the furnace or from an uncoated testing mold poured from the tapping ladle. In the case of vacuum-cast ingots the samples were extracted from the hot top through an observation window. It must be stressed that the hydrogen value here indicated cannot readily be compared with certain other published data on hydrogen contents of molten samples.[10] Many investigators have used other sampling techniques or lower extraction temperatures. Fig. 4 shows a comparison between the hydrogen content of the molten steel before and after the stream-droplet degassing, and Fig. 5 compares air-cast and vacuum-cast ingots from the same heat.

On the average, about 50 pct of the hydrogen content was removed by the vacuum treatment. It must be borne in mind that in vacuum ingot casting the molten steel may have absorbed hydrogen from the moisture of the hot top, while the hydrogen content in the main part of the ingot used for the forging may be still lower. Further progress has been made so that hydrogen contents of less than 2.0 ppm have already been achieved.

According to Sieverts, the solubility of hydrogen in molten steel decreases with the square root of the pressure[11] as shown in Fig. 6. The experimental points on Fig. 6 represent total pressure, since the partial pressure was not exactly known. In view of the short duration of the effect of the vacuum in this process it might be feared that the equilibrium could not be even approximately achieved. However, as shown in Fig. 6, in continuous production with stream-droplet degassing or ingot degassing of heavy forgings one actually arrives at the order of magnitude of these equilibrium values.

In addition to these degassing processes there is a noteworthy evaporization of volatile metals and/or oxides which collect in the filter of the pumps. An analysis of this filter dust showed:

FeO	MnO	CaO	SiO_2
17.9 pct	47.0 pct	0.5 pct	1.1 pct
Zn	Cu	Sn	Pb
1.4 pct	2.6 pct	0.2 pct	1.0 pct

It is evident that manganese, zinc, copper and tin (and perhaps other metals, too) have been vaporized from the molten steel due to their high vapor pressure.

Reports on the influence of the vacuum melting on the ingot macro-structure have appeared in technical publications.[12] However, in the vacuum casting

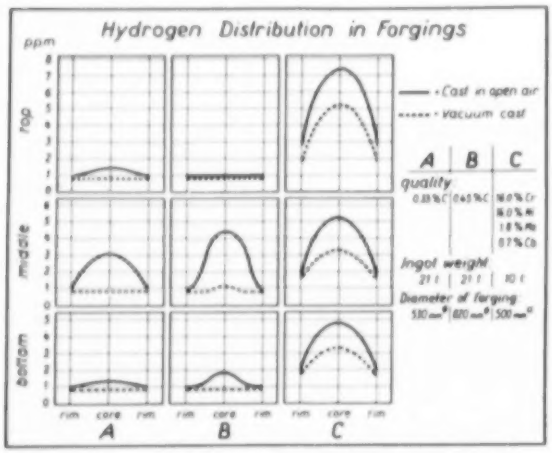


Fig. 7—Vacuum cast steel ingots show a minimum of hydrogen segregation, although both vacuum cast and air cast ingots show higher concentrations at the core than at the rim.

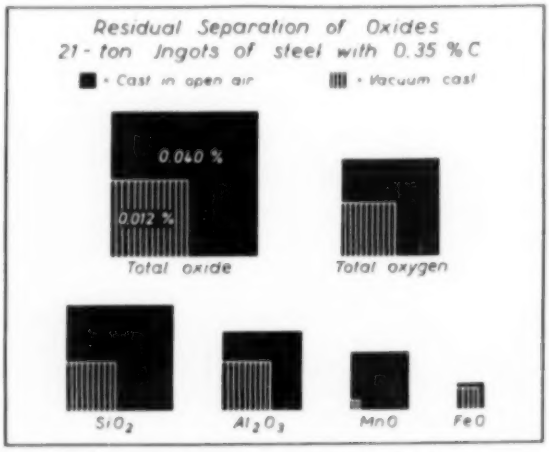


Fig. 8—The total quantity of isolated oxides in vacuum-cast ingots of 0.35 pct carbon steel was only one fourth that of air-cast ingots, and manganese oxides were practically absent.

process herein discussed, only slight effects in this respect have been observed. These might be explained by other influences, for instance, by different casting temperatures.

No evidence has been found to date that ingot segregation of carbon, phosphorus, sulphur, and the usual alloying elements is influenced by vacuum treatment at pressures around 5 mm. On the other hand, the oxygen and nitrogen contents of the forging ingots, some of which were tested in the cast condition and others in the forged condition, were definitely lower in the vacuum ingots. No significant differences were observed between the top, middle and the bottom, or between the rim and the core of the ingot. By contrast, the higher gas contents of comparable air-cast ingots revealed major differences between rim and core and between top and butt end.

Of particular interest for forgings is the question of the differences in hydrogen content which may appear over the cross-section. As a result of the solubility drop during solidification a segregation of hydrogen must be expected. However, it is difficult to measure the extent of such segregation, since a noticeable diffusion of the hydrogen does occur. In order to check the differences in the hydrogen content between air-cast and vacuum-cast ingots, the hydrogen content of the solid steel was determined. Care was taken to ensure that when the sample was taken no heating above 25°C occurred and that the analysis was made immediately thereafter. In this case the vacuum fusion method was applied. Fig. 7 shows that in the rim of forgings from 0.35 and 0.45 pct carbon steels the hydrogen content in solid condition had dropped to values below 1 ppm, which value approaches the limit of error in this method of determination. By contrast, hydrogen concentrations in the middle and core of air-cast steel ingots are higher. In the core of the middle piece, values of 3-5 ppm were established, while in vacuum steel they were around 1 ppm. Obviously, during cooling the hydrogen has diffused out from the ends of plain carbon steel forgings. Therefore, only curves for the middle sections show up the large difference between air-cast and vacuum-cast steel for forgings.

The number of micro-shrinkholes can never be entirely avoided in big forgings. But, so far as the gas content is responsible for their occurrence, their number is reduced by vacuum treatment. Another important phenomenon is the favorable influence of the vacuum treatment on the porosity of steel castings in extremely thin sections, as, for instance, the blade edges of Francis and Pelton wheels made of 13 pct chromium steel. In the case of these steels the cause could not lie in inadequate deoxidation but only in the hydrogen content. In stream-droplet degassing, applied to steel castings, it was possible to remove about 50 pct of the hydrogen content and to eliminate porosity. The reduction by 4 ppm from the level of the initial content results in sufficiently low hydrogen content to render harmless the reabsorption of hydrogen during the run through the mold. Samples taken molten in the open riser of the mold showed an average increase of about 4 ppm.

The improvement in the degree of purity achieved by vacuum casting was already demonstrated by the reduction of the oxygen content. As seen in Fig. 8 the comparison of the isolated residues in samples from vacuum and air-cast 0.35 pct carbon ingots of one heat showed that the quantity of the isolated oxides in the vacuum-cast ingots was only one fourth that of the air-cast ingots. Furthermore, major differences in the silica and alumina contents occurred and, in the vacuum ingots, manganese oxides were practically absent. Similar results were obtained in transparent-polishing tests that were carried out in the Metallurgical Institute of the Technical College in Aachen on samples of the same steel (Fig. 9).[11]

The following plant tests were carried out with a view to clarifying the very important question as to how far the liability to flaking is reduced by the decrease in hydrogen obtained in vacuum ingot casting. A number of top and bottom parts of big forgings, taken from current production, were exposed to the air immediately after forging. They were tested supersonically over the whole length, and also pickled and cut pieces broken to detect any flaky cracks. The pieces taken from the vacuum-cast ingots showed no flakes, while numerous large flakes were revealed in the air-cast ingots.

In further comparison tests of metal taken from the same heat the vacuum-cast forging was always free from flakes, while the normally air-cast forging was full of flakes. The same holds good even for 21-ton ingots made from 0.45 pct carbon steel which were forged to 28 in. diam and exposed to air immediately after forging. It is shown, therefore, that the initial aim was achieved, i.e., to avoid the tendency to flaking, even in heavy forgings.

In order to characterize the progressive development of the process, reference may be made to a number of earlier experiments carried out on rails with a tensile strength of 128,000 psi, in comparison with more recent results. One part of the melts was cast without previous vacuum treatment, the other part, after stream-droplet degassing, was cast into 2-ton ingots in air. The ingots were then rolled to rails. One half of the rails were then put into a pit and the other half laid out in the open air. All the rails in the pit were free of flakes. About 25 pct of the air-cooled rails that were from the non-vacuum-treated part of the melts showed numerous flakes over the whole length. Only about 5 pct of the air-cooled rails made from degassed steel revealed a few flakes. The reduction of the hydrogen content in the molten condition from 5.8 to 3.1 ppm had thus effected a clear reduction of the liability of flaking, but, owing to the rolling and cooling strains, it was evidently not sufficient to secure complete freedom from flakes. It was subsequently possible, by further lowering the pressure during the degassing, to attain a hydrogen content of approximately 1.8 ppm and

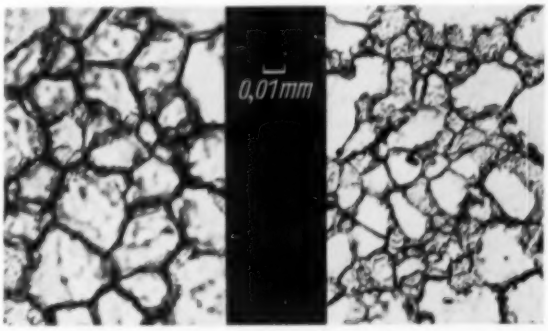


Fig. 9—These views of transparent specimens from 21-ton ingots show, left, as cast in open air with 0.010 pct O_2 and, right, vacuum cast with 0.002 pct O_2. Composition, pct: C 0.35, Mn 0.63, P 0.030, S 0.023, Si 0.038, Cr 0.14.

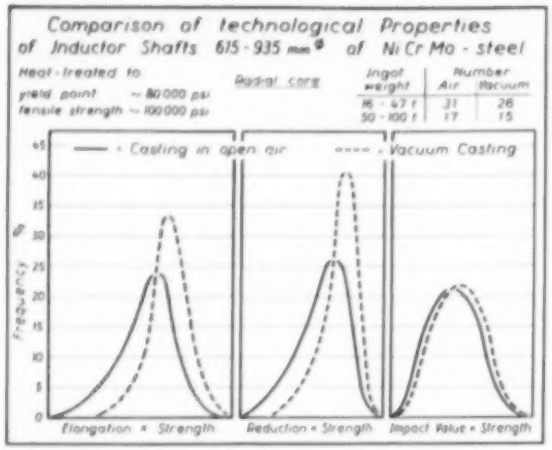

Comparison of technological Properties
of Inductor Shafts 615 - 935 mm Ø of Ni Cr Mo - steel
Heat - treated to
yield point ~ 80 000 psi
tensile strength ~ 100 000 psi
Radial core
Ingot weight
Number Air
Number Vacuum
16 - 47 t 31 26
50 - 100 t 17 15
Casting in open air
Vacuum Casting
Frequency
Elongation • Strength
Reduction • Strength
Impact Value • Strength

Fig. 10—The elongation and reduction of area are, on the average, higher in forgings of vacuum ingots than air-cast ingots.

thus complete freedom from flakes in the air-cooled rails.

This gradual progress in the rail tests was described in order to demonstrate that, despite the good results obtained, caution must still be observed when forgings are air-cooled. It is well known that liability to flaking is influenced not only by the hydrogen content, but also by working, cooling and transformation strains.[14] In some air-hardening steels for heavy forgings, this can increase the liability to flaking. In air-hardening steels, hardening strain cracks caused by surface defects may occur. For instance, air-cooled forgings of Ni-Cr-Mo steel showed hardening cracks over the whole length. The fact that they were nevertheless free from flakes is evidence of their particularly low hydrogen content after the vacuum ingot degassing. For heavy forgings made from these steels it is necessary, therefore, to interrupt the air-cooling of the piece at about 300°C and to soft-anneal it. According to the above experiences, however, this soft annealing need not be continued for as long a time as is necessary for normal air-cooled ingots to achieve diffusion of the hydrogen in the ferritic condition. After the preliminary machining, heat treatment in air or in oil can be undertaken. Flakes in the current production of forgings from vacuum ingots have never been found.

The mechanical properties are likely to be influenced by the vacuum treatment, first, by reducing defects and improving purity in connection with the reduction of oxygen values. As is shown by the pickling embrittlement, high hydrogen content also affects the toughness values. A decrease in elongation and contraction may be observed in connection with relatively low hydrogen values, although no change is shown in tensile strength.[15] For purposes of checking the results, a large-scale evaluation was carried out of tensile and notched bar impact values of radial tests of inductor shafts of Ni-Cr-Mo steel. In order to facilitate comparisons between air-casting and vacuum-casting, only forgings of similar dimensions and of the same kind of steel and melting process were used. Fig. 10 shows that on the average the elongation and reduction of area values are higher in the forgings from vacuum ingots and that their range is narrower than in the air-cast ingots. No influence was revealed in the notched bar impact values.

As no special precautionary measures were taken in the inspection tests with regard to hydrogen diffusion during sampling and storage, it cannot definitely be decided whether the established improvement of values must be attributed solely to a reduction of the hydrogen content or to differences in the degree of purity.

In respect to the supersonic recordings in these flake-free forgings a definite improvement, as a result of the application of the vacuum process, has also been established in qualities of inductor shafts, turbine rotors (some of high-temperature high-alloyed steels), backing rolls, high pressure casings, barrel shafts, rolls, dies, etc. From the outset the scrap figures were considerably lower than in the case of air-cast ingots. In the course of the application of the vacuum process to the production of still heavier ingots it proved necessary to adapt the operational methods in the steelworks to the special requirements of the vacuum casting. Following a successful termination of these efforts, surprisingly satisfactory results are now being achieved.

Since 1952 the production of vacuum steel at the Gussstahlwerk Bochumer Verein amounted to some 25,000 tons, primarily for the above mentioned forgings from ingots of up to 150 tons. In addition, some 1900 tons of high grade steel castings were made after vacuum treatment.

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The Desulfurization of Molten Iron

by J. N. Hornak and E. J. Whittenberger

THE ever-increasing demand for low-sulfur steels, together with the continual increase of sulfur in raw materials and fuels used in the open-hearth furnaces, creates ceaseless problems for both the operators and the metallurgists. Although a steel with a sulfur content as high as 0.300 pct is specified for some heats, since it doubles the speed and ease with which the steel can be machined into gears, pinions, screws, and many other products, it is, nevertheless, necessary that the sulfur concentrations be maintained at a much lower level in most of the ingot tonnage produced. It has been established that a sulfur concentration greater than 0.030 pct increases the tendency of steel to tear and crack during rolling, contributing toward increased conditioning costs and scrap losses. Sulfur also makes steel dirty and renders it unfit for many applications, especially for bearings and aircraft parts. For these reasons, sulfur is one of the greatest enemies of the steelmaker.

In most open-hearth shops, about 60 pct of the total charge consists of molten blast-furnace iron, and even though the iron may contain only 0.035 pct sulfur, it can contribute as much as 38 pct of the total sulfur input into the furnace. The balance of the sulfur comes from the following sources: fuel, 22 pct; scrap, 19 pct; limestone, 14 pct; ore, 5 pct; and other materials, 2 pct. While hot metal comprises the major part of the total charge some slag is flushed out of the furnace during the early part of the heat. This flush slag removes about 15 pct of the total sulfur that goes to the bath. The remaining or tap slag removes 32 pct, while 53 pct remains in the steel. These figures are averages and vary for individual heats and for different open-hearth shops.

Desulfurizing steel in an open-hearth furnace under the oxidizing conditions that prevail is not an economical operation. Therefore, the solution to the problem appears to be to decrease the total sulfur input. Since the hot metal is a major sulfur contributor, much can be gained by controlling its sulfur concentration, although attention must still be given to the sulfur content of the fuel, scrap, limestone, etc.

The normal approach to producing a low-sulfur iron is by special burdening of the blast furnace. Although this practice produces the desired results, it usually reduces the production rate and increases the operating cost. Hence, all recent studies have involved an external treatment of the molten iron. By *external treatment* is meant that the desulfurizing agent is added to the iron during or after casting.

It is apparent that the cost of an external desulfurizing treatment must be less than the cost of burdening the blast furnace for sulfur control. There is general agreement among open-hearth operators that, if the average iron sulfur could be maintained at about 0.030 pct, the open-hearth operator could consistently and economically produce steel to 0.030 pct sulfur. Estimates by various blast-furnace operators of the cost of burdening the blast furnace to reduce sulfur concentration from 0.050 pct to 0.030 pct varied from 40 to 60¢ per ton of iron. This, then, establishes the maximum cost for externally desulfurized iron. However, even though the average sulfur in a blast furnace using a lean burden would be about 0.050 pct, there would be many casts that would finish at 0.030 pct or less. These low-sulfur casts would not require external treatment, a factor which must be considered in cost calculations for external desulfurization.

The various ways of desulfurizing iron externally can be considered in three classifications.

Desulfurization Due to Composition Change with Temperature Drop

In reporting desulfurization by temperature drop, Herty and Gaines[1] found that the product of the percentage of manganese times the percentage of sulfur in iron was constant at 0.070 at 2450°F. If the product of these two elements is less than 0.070 at the blast furnace, no desulfurization will occur; if the product is greater than 0.070, desulfurization will occur. Based on the work of Joseph and Holbrook,[2] solubility curves of manganese and sulfur in liquid iron as a function of temperature indicate that desulfurization is achieved by the precipitation of manganese sulfide under certain conditions when the metal is chilled. Trials have shown that, under proper conditions, a blast-furnace cast of 2.75 pct manganese with 0.055 pct sulfur at 2670°F was desulfurized to 0.021 pct by decreasing the temperature about 400°F.

However, in considering the above method of iron desulfurizing, the following must be recognized:

1) The proper ratio of manganese and sulfur in the iron must be maintained to achieve desulfurization.

2) There are limitations with respect to producing very low-sulfur iron.

3) There is a danger of severe skulling of mixers and ladles.

4) There could be an adverse effect of the reduced iron temperature on the production rate of the open hearth.

For these reasons, this approach does not appear to be attractive from a commercial standpoint.

Desulfurization by Reaction Between Liquid Desulfurizers and Molten Iron

Liquid basic slags and all alkalies, whether or not they become liquid in contact with molten iron, are considered in this group:

Use of Liquid Basic Slags (Other than Alkalies): Slags containing 1/3 burnt lime, 1/3 blast-furnace slag, and 1/3 fluorspar, when used in a molten state in amounts of about 2 pct of the iron treated, are effective in desulfurizing iron to very low values. Lime-alumina slags are also effective desulfurizers. But these slags have high handling, preparation, and melting costs; and, at the maximum desulfurizing efficiency experienced, the cost of this operation exceeds the previously mentioned cost of burdening the blast furnace.

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Studies have been made with blast-furnace slag as a desulfurizing medium. Although a reduction in sulfur was obtained when the slag and metal were kept in contact for an extended period of time, little or no desulfurization was achieved by a rapid mixing of the slag and the metal. Also, it was observed that when the iron was poured from great heights into the slag, to promote rapid mixing, the temperature of the metal was reduced approximately 100°F. While the material cost is low, the use of blast furnace slag on a commercial basis does not appear attractive because of the extended period of time required to achieve desulfurization, or the excessive temperature drop that results when the metal is poured into the slag.

Use of Strong Alkalies: Strong alkalies are effective desulfurizers. Flaked caustic soda (NaOH) readily melts in contact with molten iron. Additions of caustic to the transfer ladle or at the mixer indicate that about 7 lb of caustic soda will remove about 9 points of sulfur (from 0.035 pct to 0.026 pct). The cost of this material is about 4½¢ per lb f.o.b. in carload lots. Soda ash (Na_2CO_3), on the other hand, which costs about 2¢ per lb f.o.b., is not quite as effective a desulfurizer as caustic soda and accordingly must be used in somewhat larger quantities. Even though the increased quantities required can offset the lower cost of soda ash, both soda ash and caustic soda appear attractive from a cost standpoint.

Although alkalies are effective desulfurizing agents, their wide acceptance has been precluded for the following reasons: 1) They are difficult to handle and are corrosive to refractories and surrounding equipment; 2) workers must be protected from personal contact and from the fumes developed during desulfurization; and 3) they readily decrease in efficiency and become ineffective as they become contaminated with acid slags, kish, or blast-furnace slag.

Desulfurization by Reaction Between Solid Desulfurizers and Molten Iron

Burnt lime, limestone, calcium carbide, and calcium cyanamide are but a few of the many solid reagents that have been used for desulfurizing molten iron. Some, such as burnt lime, are relatively cheap (about 1¢ per lb), while others, such as calcium carbide, are more expensive (about 6 to 7¢ per lb).

These solid reagents to be effective desulfurizers require an excessive period of contact time. When the mixing of the reagent and iron is rapid, their efficiencies have generally been very erratic. All investigations pertaining to the desulfurization of molten iron have consistently demonstrated that regardless of where the process occurs, whether in the runner or ladle at the cast house, in the transfer ladle at the mixer, or at a special treating station, thorough mixing of the desulfurizing agent and liquid iron is essential in achieving effective desulfurization. Various practices have been tried. Rapid pouring from great heights, though requiring a minimum of time, produces erratic results with regard to desulfurizing power for some of the reagents, chiefly because of the variability in obtaining intimate contact. On the other hand, mixing the reagent and the iron by purging with an inert gas requires extended periods of time. These reasons, plus excessive iron-temperature losses with either practice, make these approaches unattractive.

A current practice receiving considerable attention is a **fluidized-injection technique** that has been developed for introducing solid desulfurizing reagents at a considerable depth in the metal. Fig. 1 shows the type of equipment used. Injection by this technique provides both intimate contact and suitable mixing of the desulfurizing reagent and the molten iron, as seen in Fig. 2. Following a preliminary study in an iron foundry using the above injection technique with calcium carbide as a desulfurizing reagent, it was decided that the results obtained merited a more thorough investigation. As a result, an experimental program was designed to evaluate the effects produced by varying the initial sulfur content of the iron, the amount of desulfurizing material injected, the metal temperature at the start of the desulfurizing treatment, and the depth to which the immersion tube was injected into the molten iron. These variables were investigated for the following materials: calcium carbonate ($CaCO_3$), burnt lime (CaO), calcium carbide (CaC_2), and calcium cyanamide ($CaCN_2$). A summary of the data reveals that the desulfurizing potential of the fluidized-injector method is strongly dependent on the initial level of sulfur in the iron being treated and to a lesser extent on the amount of desulfurizing material injected. Although the measured differences for the other two variables

Fig. 1—For fluidized injection, the reagent is mixed with inert gas in this pneumatic feeder. The mixture is conveyed to the ladle through a rubber tube.

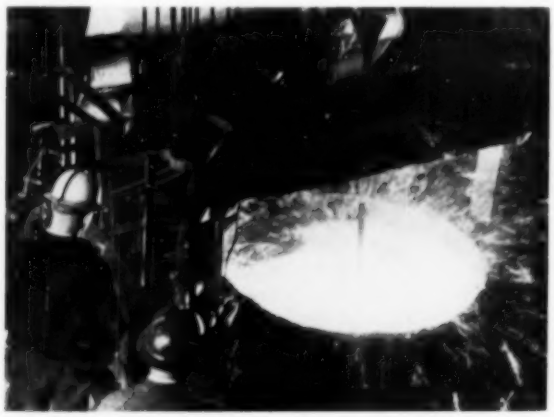


Fig. 2—The mixture of desulfurizer and inert gas is injected below the surface of the metal through a graphite injection tube. Vigorous agitation and rapid mixing with iron results.

Table I. Per Cent Sulfur Removed in Desulfurizing*

Sulfur, Pct. Before Treatment	Desulfurizing Agent	Sulfur, Pct After Treatment with 10 Lb Agent per Ton	Sulfur, Pct After Treatment with 20 Lb Agent per Ton
0.030	$CaCO_3$	0.0038	0.0050
0.030	CaO	0.0053	0.0112
0.030	CaC_2	0.0125	0.0163
0.030	$CaCN_2$	0.0148	0.0200
0.060	$CaCO_3$	0.0080	0.0172
0.060	CaO	0.0218	0.0285
0.060	CaC_2	0.0165	0.0355
0.060	$CaCN_2$	0.0205	0.0343

* Each average pct sulfur removed for ladles treated with $CaCO_3$, CaO and CaC_2 is computed from the data from four ladles; the average for those ladles treated with $CaCN_2$ is computed from two ladles each.

appear significant, the uncertainty associated with these measured differences is quite large and does not permit making precise conclusions. Table I shows the extent of the desulfurization of iron as it is affected by varying the initial sulfur content of the iron, and the quantity and type of desulfurizer used. The study showed that the injection technique is applicable for the injection of more than one desulfurizing reagent and that all, from the economical standpoint, warranted further study.

With this information as a background, the next phase of the investigation covered desulfurization studies at several plants both at the blast furnace cast house and in the transfer ladles after the open-hearth mixers. Although calcium carbide was used predominantly, burnt lime was also investigated. The studies covered the use of both a single and a double lance-injection technique. For a given desulfurizing station a fair agreement among the several plants was found in regard to the effects of the initial sulfur content of the iron and the amount of desulfurizer injected on the predicted final sulfur content of the iron. Data from all the plant trials were pooled when the same type of desulfurizing agent was used, making possible a direct comparison between the blast-furnace and the mixer transfer ladles trials. Table II is a summary of the pooled data with calcium carbide as the desulfurizing reagent. Also shown are two equations (derived from this analysis) for estimating the final sulfur content of the iron. The following conclusions can be drawn from these data:

1) More sulfur can be removed when iron is treated at the blast furnace cast house than can be removed from the iron treated in the mixer transfer ladle.

2) There is an apparent difference between the blast-furnace and the mixer trials in the relationship of the final sulfur to the initial sulfur content of the iron. The coefficients expressing this relationship indicate that for an incremental increase in the initial sulfur in the iron, more of this sulfur will be retained in the iron when treated at the mixer than will be retained when treated at a blast-furnace station.

3) A comparison between the two coefficients for measuring the relationship between final sulfur and the amount of calcium carbide injected shows that the average effect of the amount of desulfurizer on the level of final sulfur in the iron is the same for both desulfurizing stations. The best estimate of the relationship of the final sulfur content to the amount of calcium carbide injected is obtained from the average of the two coefficients. Thus for each additional pound of calcium carbide injected, one can expect to remove between 0.0013 to 0.0018 pct sulfur from the iron.

4) There was considerably more variation in the predicted average final sulfur content for those trials conducted at the blast furnace than for similar sets of conditions for ladles treated at the metal mixers. Essentially this implies that a better estimate of the final sulfur can be made when ladles are treated at the mixer. This is evident when one considers that the mixer data account for 81 pct of the variations in final sulfur as compared with 73 pct for those ladles treated at the blast furnace cast house.

The two equations derived from the pooled data for the blast-furnace and mixer trials were utilized in calculating the final sulfur contents for various levels of initial sulfur and amounts of calcium carbide injected per ton. These calculated estimates are shown as a family of curves for various initial sulfur levels in Fig. 3. The close agreement of the slopes of all the lines illustrates quite clearly the similarity of the effects of the injected desulfurizer on the final sulfur content. Plant studies, however, have shown a vast difference in the desulfurizing efficiency of calcium carbide when the treatment was conducted at the blast-furnace cast house as opposed to the transfer ladle at the open-hearth mixer. Although there is a gross difference in the iron-temperature level between these two stations, the data in no way indicate that the difference in efficiency is due to temperature alone. The results, Fig. 4, show that the injection technique, with calcium carbide as a desulfurizing reagent, should be conducted as close to the blast furnace as possible.

A series of desulfurizing trials with sized burnt lime were also conducted at the blast furnace and at the open-hearth mixer. Burnt lime was selected for this phase of the study due to its relatively low cost and due to the very favorable results obtained in the initial study. A summary of the data from these trials is presented in Table III. Also shown are the prediction equations derived from these data. In comparing the results of the regression analyses of these desulfurization trials with burnt lime, it can be concluded that the same degree of desulfurization is accomplished at the blast furnace as at the mixer station when burnt lime is used, as shown in Fig. 5. This was not the case with calcium carbide. There are slight differences in the coefficients relating to the variations of initial sulfur, amount of burnt lime injected, and final sulfur content for the two stations, but in the calculation of the average final sulfur from the prediction equations derived, the difference is only 3 points maximum. This close agreement in predicted final sulfur content between the two stations is illustrated in Fig. 5, which was developed by using the two equations derived from the data.

In the studies with calcium carbide and burnt lime discussed thus far, the injection has been conducted with a single lance, and although it was found that as much as 50 lb of desulfurizing reagent could be injected per minute, the optimum figure appeared to be in the range of 30 to 35 lb. As a result, for a ladle containing 60 tons of iron, the time for injecting about 7 lb of calcium carbide per ton of iron treated was about 15 minutes. Since it was felt that this time should be shortened as much as possible, an investigation was conducted to determine the possibility of reducing the injection time

by the use of two injection tubes. Twenty-six ladles of iron were desulfurized with calcium carbide by using the double-lance practice. The same amount of calcium carbide was injected in these trials as in previous investigations conducted in the mixer of this particular plant. The comparison of the average results for the single and double-tube injection is shown in Table IV. A reduction of 6 minutes, or 37.5 pct, in injection time was realized. At the same time, the efficiency of the desulfurizing reagent did not appear to be adversely affected. Thus, the treating time required for a ladle of iron can be controlled by: 1) the number of tons of iron treated at any one time, 2) the number of tubes used for the injection operation, and 3) (to a limited extent) the rate of feed of the desulfurizing reagent through any one tube.

Of interest also is the effect that the injection technique has on reducing the temperature of the iron during the treatment. The results of an investigation of this relationship are shown in Table V. Not only the temperature level, but also the amount and type of desulfurizing reagent are factors in the temperature drop. The iron temperature loss was also determined at one of the plants during one of the subsequent trials. The results are shown in Table VI.

Regardless of where the iron desulfurization was conducted, the composition of the slag present on the iron after an injection treatment varied considerably. This variation, it appears, depended on the amount of blast-furnace slag and/or kish that was present on the iron at the start of the desulfurizing injection. It was also observed that the resulting slag was a viscous or dry slag, and consequently, a natural slag-metal separation was obtained as the desulfurized iron was poured from the ladle. Only small quantities of the treating slag were poured off with the metal. However, whether or not any

Table II. Comparison of Blast-Furnace Desulfurization with Desulfurization after the Hot-Metal Mixer, Calcium Carbide Injected

Condition	Ladles Treated At Blast Furnace	Ladles Treated After Mixer
Number of Ladles Treated	157	128
Average Initial Sulfur, pct S_i	0.033	0.033
Average Final Sulfur, pct S_f	0.017	0.022
Average Sulfur Removed, pct	0.016	0.011
Average Amount of CaC_2 Added, Lb per Ton of Iron	6.61	6.94
	Rate of Change	
b_1, Rate of Change of S_f per Unit Change in S_i	+0.6008±0.0664	+0.8417±0.0736
b_2, Rate of Change of S_f per Unit Change in CaC_2 Injection	−0.0016±0.0004	−0.0015±0.0004
Variations in S_f Accounted for by Variations in S_i and lb CaC_2/Ton, pct	73	81
Dispersion of Observed Data Around Calculated Surface of Best Fit (Prediction Equation)	±0.0044	±0.0025

Prediction equations derived from pooled data:
Blast Furnace: pct S_f = + 0.0078 + 0.6008 pct S_i − 0.0016 (lb CaC_2/ton)
Mixer: pct S_f = + 0.0046 + 0.8417 pct S_i − 0.0015 (lb CaC_2/ton)

Table III. Comparison of Blast-Furnace Desulfurization to Desulfurization after the Hot-Metal Mixer, Burnt Lime Injected

Condition	Ladles Treated At Blast Furnace	Ladles Treated After Mixer
Number of Ladles Treated	40	21
Average Initial Sulfur, pct S_i	0.029	0.032
Average Final Sulfur, pct S_f	0.021	0.022
Average Sulfur Removed, pct	0.008	0.010
Average Amount of CaO Added, Lb per Ton of Iron	9.0	8.8
	Rate of Change	
b_1, Rate of Change of S_f Per Unit Change in S_i	+0.6889±0.1121	+0.6682±0.2324
b_2 Rate of Change of S_f Per Unit Change in CaO Injection	−0.00082±0.00048	−0.0012±0.0006
Variations in S_f Accounted for by Variations in S_i and CaO lb per Ton, pct	83	69
Dispersion of Observed Data Around Calculated Surface of Best Fit (Prediction Equation), pct	±0.0030	±0.0025

Prediction equations derived from data:
Blast Furnace: pct S_f = + 0.0087 + 0.6889 pct S_i − 0.00082 lb CaO/Ton
Mixer: pct S_f = + 0.0119 + 0.6682 pct S_i − 0.0012 lb CaO/Ton

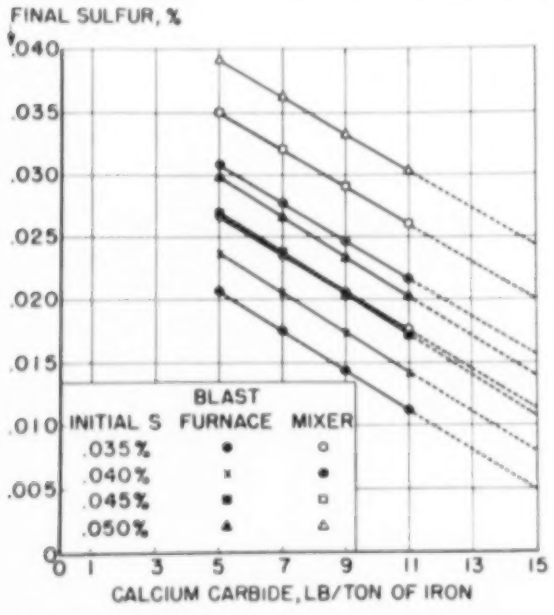


Fig. 3—Relationship between final sulfur content and amount of calcium carbide used for blast-furnace and mixer desulfurization.

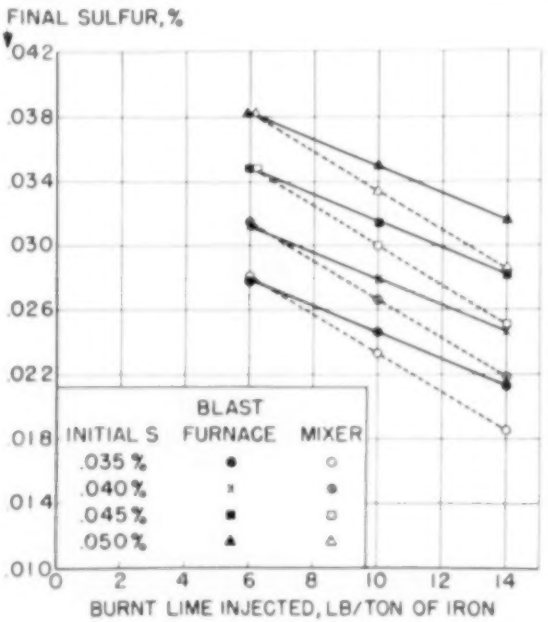
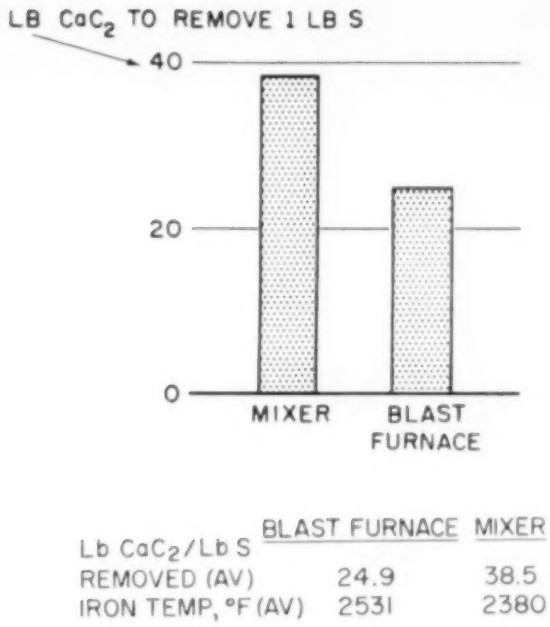


Fig. 4—Relationship between final sulfur and amount of burnt lime used for blast-furnace and mixer desulfurization.



Lb CaC_2/Lb S	BLAST FURNACE	MIXER
REMOVED (AV)	24.9	38.5
IRON TEMP, °F (AV)	2531	2380

Fig. 5—Desulfurization efficiency for blast furnace casthouse and mixer trials.

adverse effect on refractory lining resulted from the small amount of treating slag that was poured into the mixer was not determined. This phase of the problem will have to wait until a full-scale commercial trial of iron desulfurization by the injection technique is attempted.

To summarize the results of the studies that were made, the following conclusions can be drawn:

1) A technique has been developed whereby the sulfur can be controlled in a simple and efficient manner. Of significance is the fact that this control can be exercised after the sulfur level in the iron has been determined.

2) The injection technique has made it possible to obtain rather uniform results by using materials that, when added to the stream or to the bottom of the ladle, produced erratic results. This statement is made on the basis of the specific sulfur range being investigated.

3) The injection technique is applicable to more than one material. In these studies, four materials (calcium carbonate, burnt lime, calcium cyanamide, and calcium carbide) were all effectively used.

4) The injection technique does result in a loss in iron temperature. The extent of this loss is dependent on a) the temperature at which the iron is treated, and b) the amount of desulfurizer injected. The most severe temperature drop resulted from using calcium carbonate, since considerable heat was required for calcination of the material.

5) The injection time required can be controlled either by controlling the rate of feed through a single tube or by using multiple injection tubes. The maximum flow through any one tube, however, is limited.

6) There is a wide difference in material costs of the four desulfurizing reagents. In making a selection, however, considerable thought should be given to the quantity of material required both from the standpoint of the iron-temperature loss effect, and from the standpoint of time required to complete the operation.

7) The injection technique would eliminate some of the current difficulties that blast furnace operators are encountering. At the present time, considerable variation in raw materials is being experienced and, as a result, the blast furnace operator either overburdens the blast-furnace charge to produce this low-sulfur iron, or finds himself in a position where frequent corrective measures are necessary. Since there is a considerable lag in time before the corrective burden measures are effective, considerable high-sulfur iron is generally produced.

8) Last, but not least, the injection technique eliminates the need for a reladling operation to reduce the sulfur level of the iron. As pointed out, it is possible to treat the iron either in the ladle at the blast furnace or in the transfer ladle near the mixer of the open-hearth furnace.

Table IV. Single-Tube and Double-Tube Injection of Calcium Carbide to Iron in Transfer Ladles After Hot-Metal Mixer

Condition	Single Tube	Double Tube
Number of Ladles Treated	81	26
Average Initial Sulfur, pct	0.035	0.036
Average Final Sulfur, pct	0.024	0.025
Average Sulfur Removed, pct	0.011	0.011
Average Amount of CaC_2 Injected, Lb per ton of Iron	7.12	7.40
Average Injection Time, min	16	10
Average Efficiency*, pct	8.03	7.75

* Efficiency calculated on basis of 80 pct purity of calcium carbide.

Table V. Average Decrease in Iron Temperature for Two Levels of Initial Iron Temperature and Amounts of Desulfurizer Injected

Initial Iron Temperature, °F	Desulfurizing Agent	Temperature Drop, °F, After Treatment with 10 Lb Agent per Ton	Temperature Drop, °F, After Treatment with 20 Lb Agent per Ton
2350	$CaCO_3$	108.2	127.5
2350	CaO	45.0	82.5
2350	CaC_2	58.3	132.5
2350	$CaCN_2$	95.0	107.5
2600	$CaCO_3$	132.5	211.2
2600	CaO	116.2	135.0
2600	CaC_2	63.8	112.5
2600	$CaCN_2$	120.0	95.0

Table VI. Average Decrease in Iron Temperature during Mixer and Blast-Furnace Studies

Condition	Blast Furnace	Mixer
Average Initial Temperature, °F	2530	2380
Average Final Temperature, °F	2465	2335
Average Δ Temperature, °F	65	45
Average Lb per Ton	8.5	6.9
Average Time, Min	17.8	11.2
Material Used	CaO	CaC_2

Acknowledgments

We wish to acknowledge the assistance of the operating, metallurgical, and development groups at the Edgar Thomson, Clairton, and South Chicago Works as well as the Applied Research Laboratory personnel of the U. S. Steel Corp., and also the assistance of the Air Reduction Co. during the development of many phases of this investigation.

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Review of

The Effects of Hydrogen in Steel

by E. R. Slaughter

Hydrogen retained in steel may result in important defects, particularly in heavy sections of killed carbon steels and alloyed steels.

STEEL adsorbs hydrogen in processing, principally from the reaction of iron and water vapor. In the finishing operations, the reaction of steel with acid and the cathodic deposition of hydrogen during plating may introduce high concentrations of hydrogen into steel. The sources of hydrogen in steel are important in the study of hydrogen-induced defects, since certain of these defects are caused by hydrogen from steelmaking operations, while other defects are usually caused by hydrogen from other sources.

Hydrogen is responsible for four principal types of defects in steel. These defects are porosity, flaking, hydrogen embrittlement, and *delayed brittle fracture*, or *static fatigue*. However, each of these defects is not a problem in every grade of steel. This discussion will attempt to describe these four principal defects in steel, and to identify the sources of hydrogen which are most likely responsible for them.

Porosity

Hydrogen is more soluble in liquid steel than in solid steel, and it segregates by rejection from the solidified steel to the remaining liquid during solidification. In fact, hydrogen segregates in steel to a greater extent than does any other element. Therefore, the last liquid to solidify has the highest hydrogen content. Also, because the solubility of hydrogen in steel decreases upon solidification, a portion of the hydrogen may be liberated as gaseous hydrogen to produce blow-hole type porosity or aggravate center-line shrinkage.

In steel ingots, porosity due to hydrogen is particularly troublesome in the high-chromium grades. In steel castings, hydrogen can cause porosity regardless of composition.

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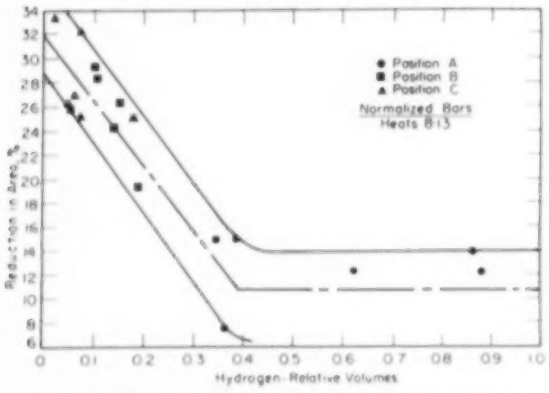

Fig. 1—Ductility, shown by pct area reduction in tensile test bars, decreases with increased hydrogen content until a minimum point is reached. The figure shows the range of values for normalized cast carbon steel.

Flaking

A very important type of defect caused by hydrogen is known variously as flaking, shatter cracks, or hairline cracks. Flakes are ruptures in massive steel billets, forgings, or rolled products. Sometimes the orientation of the flakes is random, but occasionally, the flakes are oriented with respect to the surface of the steel. Flakes are often restricted to certain regions of the steel.

It has been shown that the presence of hydrogen is a necessary condition for flaking. This hydrogen is ordinarily introduced during the steelmaking operations. In addition to the presence of hydrogen, thermal or transformation stresses are necessary conditions for flakes. For flaking to occur, some stress must exist in the steel for a period of time ranging from several hours to a day or so, while the steel is below 400 F. Hardenability has a large effect on the susceptibility of a steel to flaking, and steels with the greatest hardenability are the most susceptible.

The most obvious method for the prevention of flakes is the elimination or reduction of the hydrogen content of the steel. However, the common commercial practice for the prevention of flakes is a slow-cooling cycle. The principal beneficial effect of a slow-cooling cycle in preventing flakes is due to the increase in the temperature of transformation. Complete transformation of steel at high temperatures prevents flakes by forming a structure which is not susceptible to flaking. A slow-cooling cycle may also eliminate a significant amount of hydrogen by diffusion from a light section, but a slow-cooling cycle does not eliminate a significant amount of hydrogen from the interior of heavy sections.

Slow cooling in some cases may be only a temporary expedient for preventing flakes. The billet which is flake-free due to slow cooling may still con-

tain enough hydrogen to cause flakes after a forging operation, if the forging is not cooled slowly.

Hydrogen Embrittlement

Perhaps the most prevalent defect caused by the hydrogen in steel is the loss of ductility at low strain rates, which is called hydrogen embrittlement. While flaking and delayed brittle failure are limited to steels having considerable hardenability, hydrogen embrittlement may affect all ferritic steels and, to a lesser extent, austenitic steels. Hydrogen is unique among alloying elements, in that it causes a loss of ductility without a corresponding increase in hardness or strength. The ductility, as indicated by the reduction in area or the elongation of the tensile specimen, decreases as the hydrogen content increases until the minimum value of ductility is reached, Fig. 1.[1] This loss of ductility occurs only at moderate strain rates; usually the impact resistance of steel is not affected by the presence of hydrogen.

Any damage that occurs due to flaking is considered to be permanent. In contrast to this, hydrogen embrittlement is a temporary defect. Steel which has been embrittled by hydrogen can be restored to normal ductility by aging at low temperatures to eliminate the hydrogen. Hydrogen is lost so rapidly from light sections by room-temperature aging, that hydrogen introduced during steel making may be largely removed before the steel is fabricated or placed in service. Even at room temperature, hydrogen diffuses in steel more rapidly than does carbon at heat-treating temperatures. Therefore, because of this high diffusion rate, hydrogen embrittlement depends, not only on the hydrogen content at the time of solidification, but also on the opportunity for hydrogen removal provided by the aging time prior to fabrication or service. Thickness and temperature have very important effects upon the rate at which hydrogen is lost during aging. Sims, Moore, and Williams[1] found that aging a 1-in.-square cast steel bar for 6 hr at 400°F restored normal ductility, while a 4-in.-square required more than 100 hr at 400°F to restore normal ductility at the center of the section, Fig. 2. At room temperature, 60 days of aging was required to restore full ductility to the 1-in.-square bar, while normal ductility was not restored to the 4-in.-section by room-temperature aging for more than 3½ years,[2] Fig. 3.

Because of the very important influence of section size, it is not likely that hydrogen from steelmaking operations would be retained in light sections long enough to give difficulties during service or fabrication. Only in massive wrought sections or castings, is it likely that hydrogen retained from the steelmaking operations would cause difficulty with hydrogen embrittlement. In light sections, hydrogen embrittlement is more apt to be a temporary condition following pickling or electroplating operations.

Delayed Brittle Fracture

For the past several years, the aircraft industry has been greatly concerned over *delayed brittle fracture or static fatigue*. With the use of steel parts, heat treated to more than 180,000 psi ultimate tensile strength, brittle failures of these parts were encountered. These brittle fractures may occur when the parts are subjected to static loads far below the yield point for considerable periods of time. Service failures have been reported after delay periods of several months. In many instances, test specimens machined from the region of these failures have shown normal properties when tested in the conventional tensile test. There is general agreement that hydrogen is necessary for these failures to occur, and it is also generally agreed that hydrogen from plating or pickling operations is the most likely cause for these delayed brittle failures. The author[3] has obtained typical delayed brittle fractures of unnotched, high-strength steel specimens at stresses which were less than 10 pct of the ultimate tensile strength when the specimens were cathodically charged with hydrogen while under load. In other experiments, specimens charged with hydrogen sustained static loads for 15 days before failure.

Hydrogen may cause several types of defects in steel, and it is never beneficial. It is unique among alloying elements in that it reduces ductility without any increase in strength. However, in many grades of steel, the usual amounts of hydrogen retained from steelmaking operations do not cause any commercially important defects. Hydrogen retained in steel from steelmaking operations may cause commercially important defects mainly in killed steels which are to be fabricated in heavy sections. The tendency for the formation of hydrogen-caused defects has proven to be greater with alloy steels than with carbon steels.

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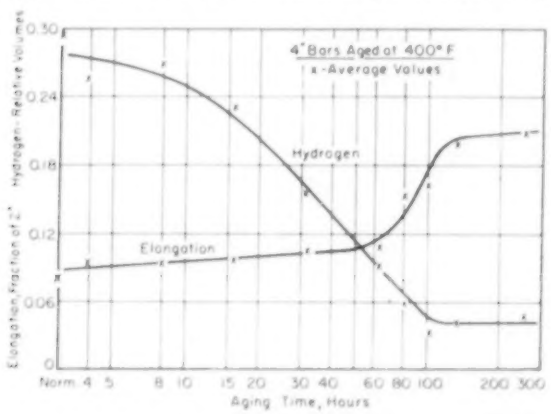

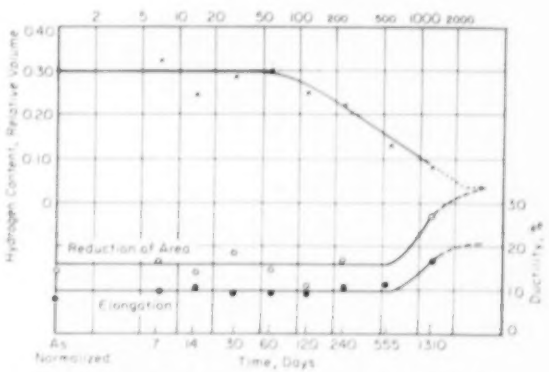

Temperature affects the rate of hydrogen diffusion and hence the time required to restore ductility of steel embrittled by hydrogen. Fig. 2 (left)—Aging requires 100 hr on 4-in. bars at 400°F. Fig. 3 (above)—Aging requires some 3½ years on 4-in. bars at room temperature.

Low Fuel Rates with Coke-Anthracite Mixtures In 3-Ft Blast Furnace

by R. C. Buehl and M. B. Royer

LITTLE experimental work has been done with blast furnaces during the past 25 years. Consequently, quantitative knowledge concerning the conditions inside a blast furnace has not advanced significantly during this period, and much less is known about blast furnace operations than other steelmaking processes. Formulas, which have been developed by statistical studies of blast furnace records, permit accurate calculations to be made of the effect of changes of raw materials, blowing rate, and blast temperature within the limits of available data. For a new raw material, however, the maximum blast temperature that can be employed and, therefore, the minimum coke rate obtainable cannot be accurately predicted from such data. Little is known about the factors that limit the maximum usable blast temperature.

Physical tests for determining the strength and stability of ore and coke are not related to conditions inside of a furnace, but are designed to measure the tendency of the material to disintegrate in transit and handling. The most desirable ore agglomerate is not definitely established even for present furnaces, fuels, and methods of operation. Blast furnaces were developed to use natural ores and there is no reason to suppose that the present design is ideal for smelting mixtures of sized ore and agglomerates. Certainly there is little basis for determining the best combination of agglomerated ore, fuel and furnace design for future operations. This is unfortunate in view of the large capital expenditures that are anticipated during the next decade for new blast furnace installations and agglomerating facilities for taconite and foreign ores.

If controlled smelting tests for comparison of raw materials are carried out in large blast furnaces, tens of thousands of tons are required to obtain significant results. The Bureau of Mines experimental blast furnace, described below, offers an opportunity to conduct actual smelting tests that require only a few hundred tons of a given ore or fuel and yield results that are indicative of behavior in a large furnace. The purpose of the series of tests was to learn how the substitution of anthracite for a portion of the normal coke charge would influence furnace operations and fuel requirements for several types of natural and prepared ores. This work was part of a cooperative project between the Bureau of Mines and the U. S. Steel Corp. for determining the suitability of an experimental blast furnace as a means of evaluating raw materials.

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Blast Furnace Design

An experimental blast furnace with a hearth diameter of 2 ft 2 in. was constructed at the Bureau of Mines, Pittsburgh in 1949 for the recovery of manganese from slag.[1] Tests of the smelting of natural ores and agglomerates were conducted in this furnace in 1953-1954 as a cooperative project with the U. S. Steel Corp. In these tests[2] the fuel rates were high. Therefore, in the latter half of 1954 it was rebuilt with an enlarged diameter and greater height and operated continuously for one year. Fig. 1 is a cross-sectional elevation of the rebuilt furnace and one of the two pebble stoves. The furnace was designed for most efficient operation based upon the experience with the previous small one. While it conforms to the general lines of an industrial-sized furnace, it is not a scaled-down model. It has a 3-ft hearth diameter and a height of 21 ft-4 in. from tuyeres to stock line.

The maximum production rate, for which the furnace could be built, was determined by the charging facilities and stoves, which were the same as for the previous furnace. The shaft dimensions were established so that either retention time for the solid stock or the gas velocities up the stack could be made the same as in an industrial furnace by adjusting the blast rate. It is not feasible to obtain comparable conditions for both factors simultaneously with a small furnace of low shaft height. To obtain a reasonable stock line diameter for the desired shaft height and hearth diameter, it was necessary to build a furnace with a somewhat smaller bosh angle and less inwall batter than the corresponding lines of a modern blast furnace.

The furnace is charged from outside the building with a conventional skip. The top is provided with 3 bells, the upper one of which rotates to avoid asymmetrical distribution of the charge in the furnace. The other 2 bells and hoppers provide the gas seal. This arrangement has an advantage over other rotating tops such as the McKee top, in that it avoids a large rotating gas seal. The furnace is equipped with 3 water-cooled copper tuyeres of 1¾ in. nozzle diameter spaced at 120° intervals around the hearth.

The hearth of the furnace is lined with firebrick, the bosh and the lower 4 ft of the stack with carbon brick, and the remainder of the stack with firebrick. Heat loss from the stack was decreased by using a backing of insulating brick as indicated in Fig. 1.

For ease in cleaning the stack at the termination of a campaign, the hearth below the tuyeres was made detachable and was suspended free of the floor by rods attached to the furnace shell. With this arrangement it was possible to have the furnace cleaned within a few hours after blowing out.

Raw Materials

Analyses of the ores and agglomerates used are given in Table I. The size range of the Oliver 13 ore was as follows: 40 to 50 pct over ¼ in., 25 to 30 pct between ¼ in. and 10 mesh, and 20 to 30 pct under 10 mesh. The fraction under 10 mesh is high for a blast furnace ore, but the ore is clay-like when wet and tends to remain agglomerated as it passes through the furnace, so that the dust loss is quite low for such a fine ore. The taconite pellets, made by the Erie Mining Co., were mainly between ⅝ and 1½ in. in diameter with about 5 pct minus 10 mesh fines which were removed by screening prior to charging the blast furnace. The Venezuelan ore had been screened at ⅜ in. to remove fines prior to shipment. The ore appeared to be too coarse for use in the experimental furnace, so it was put through a crusher set at 2 in. The fines resulting from the crushing were not removed. The sinter used with the Venezuelan ore came from the Edgar Thomson Works of the U. S. Steel Corp. and was made from a mixture of Venezuelan ore fines and flue dust. It was almost entirely minus 2 in. and was passed over a vibrating screen with a 10 mesh cloth which removed 2 to 4 pct fines prior to charging into the furnace. The screen did not do an efficient job on the wet sinter and considerable minus 10 mesh fines remained in the product.

Proximate analyses of the coke and anthracite are shown in Table II. The coke was purchased to the standard size specification 1 x 1¾ in. It was dried and the minus ½ in. fines removed prior to charging.

Both egg and stove size anthracite were used and are designated as E and S under size in the tables. The egg size passes through a round test mesh of 3 to 3¼ in. diameter and is retained on a screen with 2 7/16 in. diameter openings. The stove size is between 2 7/16 and 1⅝ in. Both sizes were, therefore, larger than the coke used in the comparison tests.

Experimental Work

Purpose and Procedure: These tests were run to determine to what extent anthracite-coke mixtures were satisfactory as a blast furnace fuel and, if possible, to develop means for improving operations with such a fuel mixture. This work is part of a larger program for studying blast furnace smelting, evaluating various ores and agglomerates, and developing an efficient low-shaft blast furnace. From tests with a Mesabi ore containing a high percentage of fines, it appeared that anthracite would prove more satisfactory with an open burden. Consequently, taconite pellets and a coarse ore-sinter mixture were tried. As cost considerations that will determine the selection of raw materials are greatly dependent on the minimum fuel rate obtainable, the efforts were directed toward obtaining this information. While it was recognized that the maximum production obtainable is also a very important consideration, the funds available for the program did not permit a determination of both the minimum fuel rate and maximum blowing rate. The Mesabi ore was run at both 800 and 1000 cfm, while for the pellets and coarse ore-sinter only 800 cfm was blown, because the charging equipment was inadequate for a higher blowing rate when using materials requiring only low fuel rates.

For tests in which the proportion of anthracite was varied, the fixed carbon contained in the fuel charged appears to be a better basis of comparison than the weight of fuel. Consequently, the coke equivalent is shown in the graphs and tables. This was calculated as the weight of coke of 91.4 pct fixed carbon content which contained the same carbon as the anthracite.

Table I. Analysis of the Ores and Agglomerates Used in Experimental Blast Furnace

	Analysis, Pct					
	Fe	Mn	SiO_2	Al_2O_3	CaO	MgO
Oliver 13 ore	56.93	1.02	9.42	2.90	0.54	0.15
Sinter	63.1	0.90	8.4	2.59	1.61	0.46
Taconite Pellets	64.1	0.27	8.95	0.4	0.53	0.51
Venezuelan Ore	65.3	0.22	1.17	1.34	0.23	0.10

Table II. Proximate Analysis (Dry Basis) of Coke and Anthracite Used in Experimental Blast Furnace

	Analysis, Pct				
	Vol. Matter	Fixed Carbon	Ash	S	H_2
Coke	1.4	91.4	7.4	0.6	0.5
Anthracite-egg	4.4	83.5	10.2	0.8	2.2
Anthracite-stove	4.9	82.4	12.7	0.8	2.0

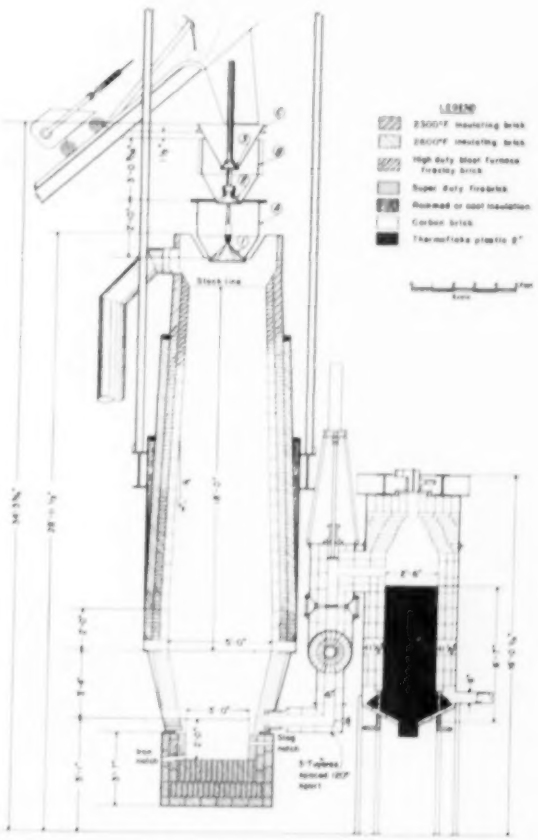

Fig. 1—Cross-sectional sketch of experimental blast furnace and one of the two pebble stoves.

Tests with Taconite Pellets: The progress of a selected period of the smelting operations on pellets is shown in Fig. 2. Prior to this test period, the furnace had been operated for two weeks on various ore agglomerates and coke. The end of this operation is shown as the first day and a half on the chart. Egg-size anthracite was then substituted for 10 pct of the coke, after which the proportion of anthracite was raised in 10 pct increments to 40 pct. After steady operations were achieved, the burden ratio was increased as shown on the chart. For the three-and-a-half-day period during which the burden ratio was 1.90 to 2.10 inclusive (Oct. 5 to 8), the average fuel rate was 1,517 lb per net ton, equivalent in coke rate to 1,464. The operations were satisfactory up to an ore to fuel ratio of 2.10, but above this ratio the silicon and sulfur content of the metal were variable, indicating that the furnace was cycling hot and cold. At burden ratios of 2.175 and 2.25, a fuel rate of 1,295 and equivalent coke rate of 1,250 lb per net ton was obtained. At 2.325 burden ratio the furnace operated poorly and the stock column became impervious to gas during a transition to Venezuelan ore-sinter mixture, necessitating a shutdown.

The chart shows that the operations on 40 pct egg-size anthracite were satisfactory at fuel rates between 1,450 and 1,500 lb per net ton, and the use of this proportion of anthracite was in no way detrimental. For a period of three days, from noon of October 4 to noon of October 7, the sulfur content of most of the casts was near 0.025 pct, which demonstrates smooth furnace operations at the low fuel rate.

In a later series of tests, not included in Fig. 2, operations were succesful on a fuel consisting of 60 pct anthracite 40 pct coke at a fuel rate down to 1,427 lb per net ton, equivalent on a fixed carbon content basis to 1,350 lb of coke per net ton. During two days of such operations the average top temperature was between 400° and 500°F and often decreased to less than 300°F after a charge was dropped, even though no water was charged and the moisture content of none of the raw materials exceeded 4 pct. The CO to CO_2 ratio in the top gas was around 1.6. This indicates that, in spite of the low height of the furnace (21 ft, 4 in. working height), the heat content and reducing power of the gas were efficiently utilized with this charge material. When the proportion of anthracite was increased to 100 pct at a fuel rate of 1,465 lb per net ton, equivalent to 1,335 lb of coke per net ton, the stock hung in the furnace. This low fuel rate could not be maintained with 100 pct anthracite.

Table III summarizes the tests in which taconite pellets were smelted with various proportions of anthracite. The tests are arranged in order of increasing proportion of anthracite at various burden ratios. They show that at a constant burden ratio and blowing rate, the use of 40 to 60 pct anthracite resulted in the following advantages for the small furnace overall coke operation:

1) The average sulfur content of the metal was maintained at a lower level even though the anthracite had slightly higher sulfur content than the coke.

2) Metal of satisfactory analysis could be obtained at lower blast temperatures (about 50 to 100°F less) even though the fixed carbon content in the anthracite was only 83.5 pct compared with 91.4 for the coke.

3) Production was higher with the anthracite-coke mixtures than with all-coke at the same blowing rate.

When the fuel consisted of 40 to 60 pct anthracite and the remainder coke, good operations were obtained at fuel rates around 1,450 lb per net ton. This fuel rate is about 100 lb per ton less than obtained with an all-coke fuel even though the anthracite had a lower carbon content than the coke. The results show that a small experimental furnace of low shaft height can operate efficiently at low fuel rates when obtaining good utilization of the heat and reducing power of the furnace gas.

Tests with Coarse Venezuelan Ore and Sinter: The ore burden consisted of 50 pct coarse Venezuelan ore (plus ⅜ in.) and 50 pct sinter obtained from the Edgar Thomson Works of the U. S. Steel Corp. The progress of this operation is shown in Fig. 3. During the first 2½ days of these operations, the fuel was entirely coke. The proportion of anthracite was then increased in steps until the fuel consisted of 40 pct egg-size anthracite. After two days of operation

Table III. Smelting Taconite Pellets with Anthracite-Coke Fuel in Experimental Blast Furnace

Date	Period Length, Hrs.	Anthracite in Fuel, Pct	Anthracite in Fuel, Size	Burden Ratio, Ore/Fuel	Fuel Rate, Lb/Ton Hot Metal, Theo.	Fuel Rate, Lb/Ton Hot Metal, Actual	Fuel Rate, Lb/Ton Hot Metal, Coke Equiv.	Hot Blast Temp. °F.	Furnace Prod., Metal Tons/24 Hrs.	Furnace Prod., Slag Lb/Ton Metal	Slag Basicity, CaO + MgO / SiO_2 + Al_2O_3
9-16	24	0		1.8	1685	1587	1587	1385	12.48	700	1.24
9-29-30	35	0		1.8	1685	1682	1682	1350	12.31	812	1.18
10-1	24	10	E[1]	1.8	1685	1654	1640	1400	13.13	845	1.20
10-2	24	25	E	1.8	1685	1697	1658	1320	12.75	825	1.23
10-3-4	32	40	E	1.8	1685	1613	1556	1305	13.28	822	1.22
9-17-18	46	0		1.9	1595	1550	1550	1465	13.32	819	1.16
11-3	14.5	18	S[2]	1.9	1595	1475	1450	1310	14.72	839	1.18
10-4	24	40	E	1.9	1595	1517	1463	1355	14.14	832	1.25
9-19-22	72	0		1.95	1555	1620	1620	1495	13.04	782	1.18
11-3-4	32.5	40	S	1.95	1555	1544	1490	1460	15.95	822	1.18
11-10	10	0		2.0	1515	1645	1645	1550	14.04	701	1.16
10-5-6	32	40	E	1.97	1535	1519	1466	1445	14.22	844	1.21
11-11	17.5	75	E	2.0	1515	1502	1404	1525	15.37		1.17
11-12	22.5	100	E	2.0	1515	1465[5]	1335	1600	15.85	875	1.25
11-21-22	30	0		2.08	1455	1655	1655	1600	13.88	794	1.18
10-7-8	33	40	E	2.07	1470	1521	1468	1490	14.46	852	1.15
11-5-6	33	60	E	2.09	1450	1427	1350	1575	17.18	836	1.23
10-9-10	36.3	40	E	2.21	1370	1295	1250	1555	16.60	820	1.30
11-7-8	33	60	E	2.24	1355	1478[4]	1400	1590	15.38	808	1.22

[1] Egg size anthracite.
[2] Stove size anthracite.
[3] Stock column became impregnable to gas flow, causing shutdown subsequent to data period.
[4] Stock column hanging—slipped off—dropped back to lower burden ratio.
[5] Gas analyzer not functioning properly.

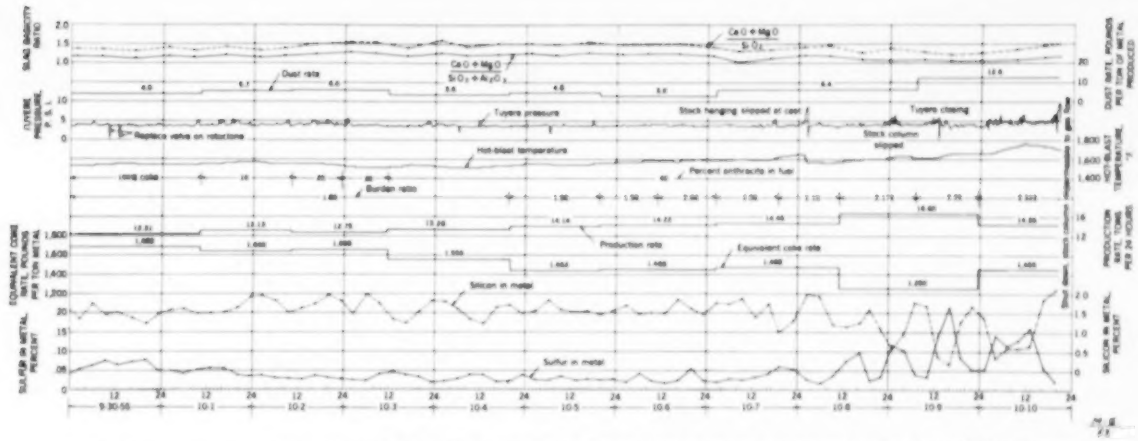

Fig. 2—Graph of operating data and results of smelting taconite pellets with anthracite-coke mixtures in experimental blast furnace.

the smaller, stove-size, anthracite was substituted for the egg-size and continued until the end of the test. The proportion of anthracite was subsequently raised to 50 and 60 pct. At this point the operation had to be terminated because of leaking tuyeres which were cut by metal runback that occurred when the air blast to the furnace dropped off suddenly because of a power failure. The test results on this ore-sinter mixture are summarized in Table IV.

Tests with Mesabi Ore: The smelting of Oliver 13 ore with coke and coke-anthracite mixtures has been described elsewhere.[8] Consequently, only a summary of the results will be given in this article. The operations were carried out at fuel rates of 2,000 to 2,200 lb per ton of metal obtained with blast temperatures of 1,300 to 1,500°F. The operations were successful with anthracite proportions up to 40 pct of the fuel, although even 10 pct anthracite resulted in more fluctuation in tuyere pressure than obtained with coke. When the proportion of anthracite reached 50 pct, the descent of the furnace charge became irregular.

Results

Comparison of Raw Material: The hot blast supplies an important fraction of the heat for smelting and so must be considered in any comparison of fuel rates. Fig. 4 shows the variation of fuel rate with hot blast temperature for the various combinations of ores and fuels investigated. Low fuel rates at low or moderate blast temperatures indicate efficient utilization of the heat and reducing power of the stack gases. Consequently, the closer the curves are to the lower left-hand corner of the diagram, the more efficient are the furnace operations, provided the slag volumes are comparable.

Taconite pellets were smelted with coke at a fuel rate of 1,550 lb per net ton for a blast temperature of 1,500°F. The corresponding fuel rate for Oliver 13 ore at 1,500°F blast temperature was 2,130 lb per net ton. The slag rate for the Oliver 13 ore was about 1,150 lb per ton against 750 lb per ton for the taconite pellets, and this difference of 400 lb would account for about 170 lb of coke per ton of metal according to Flint's Multiple Correlation Formula.[4] The large additional reduction in fuel rate of 410 lb per ton would appear to be due to increased efficiency in the utilization of heat and reducing power of the gas, because of improved distribution of the charge in the furnace. For the Erie pellets a further saving of 150 lb of fuel per ton was obtained through the use of anthracite as 40 to 60 pct of the fuel.

The fuel rate for the Venezuelan ore-sinter mixture is above that for the pellets even though the slag volume was appreciately less with the Venezuelan ore mix.

The tests demonstrated that with prepared ore, anthracite could supply 60 pct of the fuel requirements of the experimental blast furnace without any adverse effect on the operations. Tests at higher percentages of anthracite were of too short duration to be conclusive. A large furnace imposes a more severe crushing load and greater abrasion of the fuel in the raceway in front of the tuyeres and, therefore, it should not be concluded from these tests that so high a proportion of anthracite could be used in a large furnace. Anthracite offers attractive possibilities if the cost is competitive with purchased coke.

Anthracite showed advantages over coke in the experimental operations. The sulfur content in the metal was slightly lower when anthracite was used, even though the coal contained more sulfur than the coke. A saving of fuel of about 100 lb per ton of metal resulted from the use of anthracite as 40 to 60 pct of the fuel burden, although the anthracite had a lower fixed carbon content than the coke (83

Table III. (Cont)

Dust Loss Lb/Ton Metal	Metal Analysis, Pct Si	Metal Analysis, Pct S	Flue Gas Analysis, Pct CO	Flue Gas Analysis, Pct CO_2	Flue Gas Analysis, Pct H_2
6.0	1.43	.057	29.7	14.6	1.11
4.0	1.48	.059	30.0	13.9	1.25
5.7	1.68	.037	29.6	14.8	1.29
6.0	1.67	.031	29.8	15.3	1.57
3.6	1.52	.030			
6.5	1.50	.051			1.19
6.0	1.26	.070	27.6	15.5	1.88
4.8	1.56	.028	29.9	15.3	1.77
7.0	1.45	.073			1.10
4.5	1.18	.052	26.2	16.3	1.85
4.0	0.84	.121	29.1	15.6	1.27
3.0	1.59	.031	29.7	17.3	1.89
2.7	1.09	.057	23.1	15.7	2.60
5.0	.88	.067	24.5	15.6	3.24
7.5	0.94	.114	29.7	13.5	1.39
6.4	1.39	.051			2.07
2.3	1.07	.041	25.5	15.9	2.23
12.6	1.20	.080			2.13
9.9	.95	.073	26.6	15.6	2.19

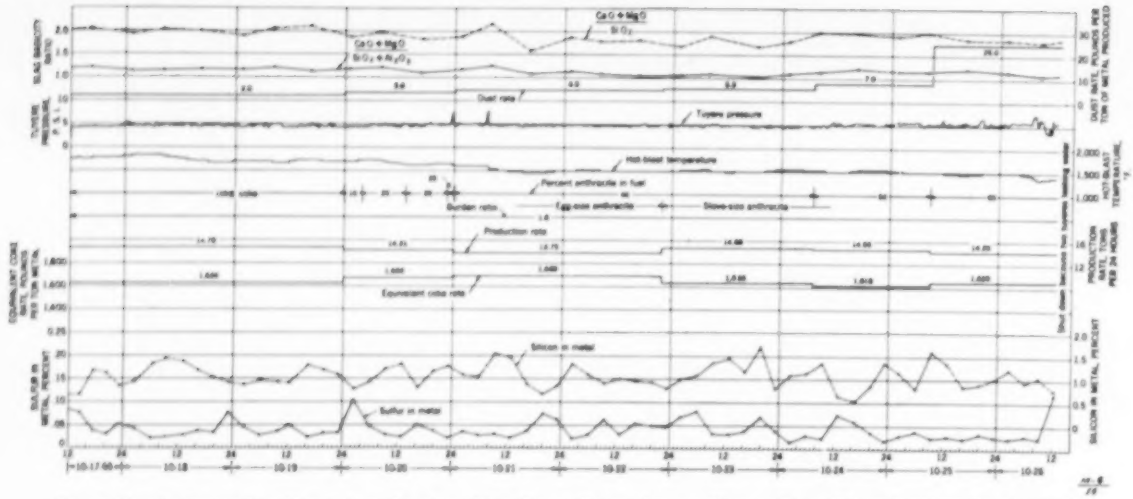

Fig. 3—Graph of operating data and results of smelting 50 pct Venezuelan ore-50 pct sinter with anthracite-coke mixture in experimental blast furnace.

against 91) and was weaker as judged by the high temperature degradation tests. The anthracite had a much higher bulk density than the coke (59 against 38 lb per cu ft). A charge containing 2 parts of pellets and 1 part of fuel by weight had a bulk density of 92 lb per cu ft when anthracite was used as compared with 65 lb per cu ft for pellets and coke. If anthracite were substituted for coke, the volume of a round of charge would be only 71 pct of that normally charged. At the same burden ratio and blowing rate, the retention time of the charge in any part of the furnace is 41 pct greater with anthracite as the fuel than with coke. The longer retention time could result in more complete heating and reduction of the ore prior to its arrival in the high temperature zone of the bosh. The increase of retention time of the ore in the furnace when anthracite replaces coke probably accounts for most of the decrease in fuel rate. Another important factor is the extent to which carbon dioxide, resulting from the reduction of ore in the stack of the furnace, will react with the fuel to form carbon monoxide. This reaction, not only consumes fuel, but also absorbs heat. During the anthracite tests the top gas contained more CO_2 and less CO than with the coke, showing that the reactivity of the fuel may be important. These results also suggest that lower fuel rates might be obtained with a dense coke than one of low bulk density.

The coke rate data give an insight into gas-solid contact and channeling in the shaft for different types of raw materials. Fig. 4 shows the slope of the curve of fuel rate vs. blast temperature that is calculated from Flint's study.[4] The slope of the curve for the Oliver 13 ore agrees well with Flint's correlation at blast temperatures above 1,550°F. However, the experimental curve is very much steeper for this ore at lower blast temperature. This is also true for the Erie Mining Co. pellets. In order to account for such a steep slope by heat balance calculations, it is necessary to assume that the fuel rate is limited by thermal requirements in the high temperature zone of the hearth and bosh and that the amount of direct reduction in this zone does not change significantly with fuel rate. The low slope of the Mesabi ore curve above 1,550°F means that a large change in blast temperature and, therefore, heat input to the high temperature zone is necessary to compensate for a small decrease in coke rate. This implies that the thermal requirement for smelting in the high temperature zone is increasing as the fuel rate decreases. From this it appears that more unreduced ore reaches the fusion zone per ton of metal at low coke rates than at high rates for this type of charge; thus, more endothermic direct reduction occurs in the hearth. At low fuel rates the volume of gas coming into contact with the ore is not sufficient to complete the reduction in the shaft. Because of poor distribution of solids in the shaft, much of the gas passes upward without effectively heating or reducing the ore. The minimum fuel rate is dependent on gas-solid contact in the shaft of the furnace. For Mesabi ore, at fuel rates above the break in the curve (2,050 lb per ton), the volume of

Table IV. Smelting Venezuelan Ore-Sinter (50-50 Mix) with Anthracite-Coke Fuel in Experimental Blast Furnace

Date	Period Length, Hrs.	Anthracite in Fuel, Pct	Anthracite in Fuel, Size	Burden Ratio, Ore/Fuel	Fuel Rate, Lb/Ton Hot Metal, Theo.	Fuel Rate, Lb/Ton Hot Metal, Actual	Fuel Rate, Lb/Ton Hot Metal, Coke Equiv.	Hot Blast Temp. °F.	Furnace Prod., Metal Tons/24 Hrs.	Furnace Prod., Slag Lb/Ton Metal	Slag Basicity, $CaO + MgO$ / $SiO_2 + Al_2O_3$
10-16	24	0		1.7	1780	1692	1692	1645	13.33	558	1.06
10-17-19	62	0		1.8	1685	1630	1630	1730	14.78	493	1.17
10-20	33	20	E	1.8	1685	1695	1665	1670	14.31	585	1.15
10-21-22	47	40	E	1.8	1685	1730	1669	1505	13.75	655	1.12
10-23-24	33	40	S	1.8	1685	1695	1635	1515	14.68	683	1.07
10-24-25	38	50	S	1.8	1685	1692	1618	1520	14.55	593	1.14
10-25-26	24	60*	S	1.8	1685	1729	1639	1475	14.20	720	1.18

* Forced shutdown at this anthracite burden because of water leak in two tuyeres.

gas is sufficient for satisfactory reduction in spite of the waste of a large fraction due to channeling. The Oliver 13 ore requires about 50 pct more reducing gas produced at the tuyeres per ton of iron than the taconite pellets, which give better access of gas to the ore layers because of their large uniform size. As the pellets, fuel, and flux were of essentially the same size, segregation tended to be minimized and what occurred should have little effect on resistance to gas flow. Gas distribution should be very uniform with the pellet charge.

Comparison with Commercial and Low-Shaft Blast Furnaces: The experimental furnace is compared to a commercial furnace and the low-shaft furnace at Liège, Belgium in Table V. The method of tabulation and the results for commercial operations (Edgar Thomson Nos. 1 and 2) were taken from an article by Hogberg.[5] Data on the Liège low-shaft furnace are from Coheur's article.[6] The production of the experimental furnace was limited by the capacity of the charging equipment, and it is believed that a considerably greater output could be obtained from this furnace. Even so, the experimental furnace was run at a much higher production per cu ft of working volume than a commercial furnace, as shown in the table, without sacrificing the low fuel rate or desirable metal analysis.

Heat loss from the high temperature zone of the furnace, that is, hearth, bosh, and tuyeres, appears to be more significant than the total heat loss and is, therefore, reported in Table V. The bosh and tuyere losses for the experimental furnace were determined by measurement of temperature rise of the cooling water. The hearth loss was estimated from measurements of surface temperature. Unfortunately, the heat loss for the commercial furnace is not known; so, it was assumed to be the same as for a German furnace of similar size on which data have been reported.[7] The table shows that the heat loss per ton for the experimental furnace (about 1,200,000 Btu) is about ten times the estimated value for a commercial furnace. The heat loss was also expressed as, that decrease in hot blast temperature for which the change in heat content of the hot blast would be equal to the heat loss. For the tests on 50 pct Venezuelan ore-50 pct sinter and on taconite pellets, this equivalent decrease in hot blast temperature amounts to about 680°F; so, the blast temperature corrected for heat loss is 930°F for the conditions reported in this table. For a commercial furnace the correction of blast temperature for heat loss would be about 70°F. The hot blast temperatures were not stated for the commercial practice summarized in Table IV but were probably about 1,000°F; so, the corrected blast temperatures would

Table IV. (Cont)

Dust Loss Lb/Ton Metal	Metal Analysis, Pct		Flue Gas Analysis, Pct		
	Si	S	CO	CO_2	H_2
1.4	1.00	075			1.39
2.4	1.05	039	29.9	10.0	1.41
3.3	1.06	043	29.6	9.7	1.82
4.6	1.02	083	29.3	10.3	2.15
5.3	1.06	044	30.3	10.9	2.30
7.9	.98	040	28.9	12.0	2.69
12.6	1.04	027	28.9	12.3	2.91

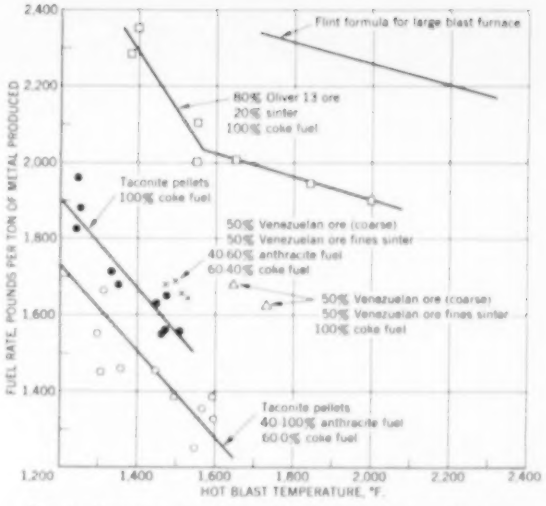

Fig. 4—Variation of fuel rate with hot blast temperature for the combinations of ores and fuels in experimental blast furnace.

be comparable with those for the experimental blast furnace operating on prepared burdens.

Comparison of coke rates for the Bureau of Mines furnace and the Edgar Thomson furnaces, both working on unprepared Mesabi ores, shows that the small furnace had a considerable higher coke rate with a higher corrected blast temperature. On the other hand, the small furnace compared well with commercial practice on prepared burdens, if the charge of coarse ore and nodulized fines in commercial practice is assumed to be roughly equivalent to 50 pct coarse ore and 50 pct sinter in the small furnace, and 95 pct coarse Mesabi ore with sintered fines is compared with 100 pct pellets. If anything, it would be expected that commercial furnaces should show a lower coke rate than the experimental furnace, for identical burdens. From this it appears that taconite pellets should be a superior feed material that would lead to a coke rate below 1,400 lb per ton of metal in commercial practice.

The Bureau of Mines experimental furnace with a working height of only 21 ft-4 in. from the tuyeres to stockline is a low-shaft furnace similar in many ways to the one at Liège, Belgium, with a corresponding height of 16 ft-4in., although the latter furnace had considerably less working volume per sq ft of hearth area. The work at Liège has been directed toward the smelting of low-grade ores of small particle size with small size coke. The coke rate is high and the production rate per sq ft of hearth area is low compared with the Bureau of Mines furnace operating on prepared burdens. The coke rate for the Liège furnace would have been still higher if it had been operated to produce a low sulfur product instead of metal carrying 0.14 to 0.2 pct sulfur. From these results it appears that, for conditions in the United States, it would be more economical to operate a low-shaft furnace on a prepared burden rather than for direct smelting of low-grade ores. Considering an ore which can be concentrated, the saving in coke (figured at $14 per net ton) accomplished by charging pellets of concentrate instead of fine ore would amount to about $7 per ton of metal or $4.70 per ton of pellets. This is considerably more than the cost of concentrating and pelletizing ore on a larger scale.

Table V. Comparison of Commercial Blast Furnace, Liège Low-Shaft Furnace, and Experimental Furnace

Furnace	Edgar Thomson Nos. 1 and 2			Bureau of Mines Experimental Furnace			Liège Low Shaft Fce. (Oval)
Hearth diameter, ft				3			9.8 x 3.9
Hearth area, sq ft	27.5			7.06			34.2
Height, tuyeres to stockline, ft	594			21.25			16.3
Working volume, cu ft	80			326			560
Ratio, working volume to hearth area	44,850			46.2			16.4
	75.5						
	100 Pct Unprepared Mesabi Ore	Coarse Mesabi Ore and Nodulized Fines	95 Pct Coarse Mesabi 5 Pct Sintered Fines	100 Pct Unprepared Mesabi Ore	50 Pct Coarse Ore 50 Pct Sinter	100 Pct Pelletized Taconite	Fine Low-Grade Ore and Small Coke
Net coke rate-lb/net ton iron	1766	1624	1461	1950	1690	1430	2400
Blast rate, total cfm	86,980	88,770	84,600	1000	800	800	3100
Per sq ft hearth area	146	149	142	142	113	113	91
Iron production rate, net tons/day:							
Total	1400	1591	1632	12.5	14.4	16.2	40
Per sq ft hearth area	2.36	2.68	2.75	1.77	2.04	2.30	1.17
Per 100 cu ft working volume	3.12	3.55	3.64	3.83	4.42	5.0	7.14
Metal Analysis: Si				1.6	1.0	1.2	0.5 to 1
S				0.03	0.04	0.04	0.14 to 0.2
Heat loss from hearth, bosh, tuyeres:							
Per min in 1000 Btu	129			11.2			
Per net ton in 1000 Btu/ton	133	117	114	1290	1120	996	
Equiv. decrease in blast temp., °F	70			540	680	680	
Actual blast temp., °F				1840	1610	1610	
Blast temp. corrected for heat loss, °F				1300	930	930	

The authors believe that, to make a low-shaft blast furnace operate efficiently, it is necessary to use raw materials of proper and uniform size in a furnace with suitable charging equipment so designed that the descending charge will consist of a uniform mixture of ore, fuel, and coke in respect to size as well as weight pct. The gas ascending through the furnace will then have a reasonably uniform distribution, permitting rapid heating of the charge and reduction of the ore. As such rapid heating and reduction are essential for the operation of a low-shaft furnace, good sizing of the ore appears more important for such a furnace than for a standard blast furnace. However, most of the efforts of various groups working on low-shaft blast furnaces have been directed to the use of fine unsized ores.

The results indicate that furnaces of somewhat lower working height than present furnaces, could operate efficiently on pellets at production rates per sq ft of hearth comparable to a modern furnace.

The use of such furnaces with a high proportion of anthracite as the fuel, might prove attractive for emergency periods when rapid expansion of steel production is required. Use of anthracite would eliminate the need for concurrent expansion of coke oven facilities in direct proportion to the increase in iron production. The furnaces could be put into operation more rapidly than conventional furnaces and would require less materials for construction.

Conclusions

1) An experimental blast furnace of 3-ft hearth diameter has been operated successfully for the comparison of blast furnace ores and fuels. The operating characteristics gave a useful insight into the factors that control blast furnace performance. This research has indicated methods for improving commercial operations that justify continuation of the program.

2) A coke rate of 1550 lb per net ton of metal for a charge of taconite pellets indicates that this material is a superior feed for blast furnaces. A charge of 50 pct coarse Venezuelan ore and 50 pct sinter had a coke rate slightly higher than for the pellets even though the slag volume was lower. Unsized Mesabi ore required about 2000 lb coke per ton. With the latter ore, the fuel rate was 200 to 300 lb higher than for a large blast furnace smelting similar ore.

3) Anthracite coal was satisfactorily substituted for coal up to 40 pct of the fuel requirement with Mesabi ore and up to 60 pct of the fuel with the prepared ores. When smelting pellets, the use of anthracite for part of the fuel resulted in lower fuel rates, about 1450 lb per ton, and higher production rates at constant blowing rate. Sulfur content of the metal was somewhat lower when anthracite was used, even though the anthracite analyzed slightly higher in sulfur than the coke it replaced.

4) Relations between fuel rate and blast temperature, together with other operating characteristics indicate that much of the chemical and heating value of the fuel is wasted through channeling of gases in the shaft when ores of small size are used in conventional blast furnace practice. Coarse ores not only result in more efficient utilization of gas but also permit greater advantage to be taken of hot blast temperature to lower the coke rate.

5) The successful operation of this furnace of 21 ft 4-in. working height suggests that commercial operation at high production rates and low fuel consumption could be obtained with furnaces substantially lower than present blast furnaces if suitably prepared ores were used. A uniform size of raw materials is desirable for efficient smelting in a low-shaft furnace. Construction and operating economies arising from the use of a shorter furnace should offset the cost of beneficiating the ore.

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How High Grade Iron Ores And Agglomerates Will Affect Coke Rates

by John Griffen

ALL indications point to revolutionary changes in the character of the iron-bearing raw materials which will be made available to the blast furnaces of the United States during the next five years. The anticipated shrinkage in the production of the Lake Superior ranges coupled with the increased needs for hot metal to support the anticipated increases in steel ingot production by 1960, are expected to result in the use of considerable tonnage of much higher grade imported ore and the beneficiation of existing ores by sintering or other agglomerating processes.

By 1960 it is probable that Lake Superior ores will constitute only about 45 pct of total requirements, while high-grade imported ores — mainly from Quebec-Labrador and South America — will be 30 pct, and pellets from Minnesota taconite and Michigan jasper concentrates will approximate 13 pct of the total.[1] Thus, these high-grade raw materials will, on the average, represent nearly half of those used, particularly in steel producing areas in the northeastern part of the country. It is probable that a large proportion of the finer Mesabi ores will be screened at about ⅜-in. and the fines sintered or otherwise agglomerated. By 1960, it is possible that as much as one-half the Lake Superior ore supply, or roughly one-quarter of the total supply, will be so beneficiated.

Because of the reduction in slag volume resulting from these higher grade raw materials, the coke rates will be reduced and furnace output will be increased. Due to the inter-relationship of these two phases of furnace operation, and the fact that the physical qualities of the new raw materials may permit higher efficiency because of better gas-solid contact, much experimentation will be needed to develop optimum practice and the most economic balance between coke rate and rate of production. However, enough has already been published on the performance of furnaces with a number of these new raw materials to indicate the minimum improvements in coke rate that can be expected. It is the purpose of this paper to collect and summarize the data now available and point to some of the problems to be solved to obtain the maximum benefits from these new iron-bearing raw materials.

Quebec-Labrador Ore

In 1955, the Iron Ore Co. of Canada loaded out 7.721 million gross tons of ore from its dock at Seven Islands,[2] and by 1960 shipments may reach 25 million tons annually. Present knowledge on this ore indicates that its size characteristics and moisture content are similar to Mesabi ore, but its natural iron is much higher and its silica content about one-half that of Mesabi.

A number of northeastern furnace plants are receiving considerable quantities of this ore. Strassburger[3] states, "At Weirton, at the present time, we are using about 40 pct Labrador ore in our blast furnaces. This ore is averaging about 54 pct iron and 5 pct silica. The operating results with Labrador ore in the burden have shown an increased iron production of about 10 pct with a decrease of almost 300 lb in limestone and over 100 lb of coke per ton of iron."

The above would indicate a reduction in slag volume of about 330 lb per ton of iron which would result in a saving of about 135 lb of coke per ton of iron, or a 7.5 pct reduction in coke rate. With slag volume reduced, probably, to about 800 lb per ton of iron, proper desulfurization may become a problem unless relatively low sulfur coke is utilized. Otherwise, adjustment of slag composition and temperature must be made to obtain the desired sulfur in the iron.

Based on Weirton's experience with about 40 pct Labrador ore, the use of about 50 pct of this ore and 50 pct of average Lake Superior ore should give about 12 pct increase in iron production and a reduction of 9 pct in coke rate.

Strassburger[3] further states, "With the results obtained from the use of a proportion of higher grade ore, we are convinced that all of the iron ore charged into a blast furnace should be upgraded for optimum results." He also suggests that the steel companies should agglomerate the fine ores into sinter or pellets so as to provide materials that will give good gas-solid contact and still further increase efficiency and reduce coke rate.

It is probable that, should the −⅜ in. portion of an ore burden consisting of one-half normal Mesabi ore and one-half Labrador ore be sintered, the further increase in iron production and reduction in coke rate would be nearly as much as that shown later for normal Mesabi ore where the −⅜ in. has been sintered, i.e., at least a 15 pct increase in iron production and a 14 pct reduction in coke rate.

Venezuela—Orinoco Mining Co.

This company shipped about 3.4 million gross tons in 1954, and shipments for 1955 should be about 7 million gross tons. This ore is quite high grade, analyzing about 63.5 pct iron, dry basis, and about 58 pct iron, natural basis.[4] Silica is extremely low, varying from 0.4 to 2.3 pct, while alumina varies from 1.0 to 1.7 pct. The alumina-silica ratio is high, varying from 2 to about 2.6.

One furnace plant on the eastern seaboard has been operating on 65 pct Orinoco ore and 35 pct Peruvian ore which is also high-grade, analyzing

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about 4.5 pct silica and 1.0 to 1.25 pct alumina. The Peruvian ore is quite coarse and lumpy, while the Orinoco ore is fine, and flue dust production has been higher than normal. A blast temperature above 1400°F has been possible. With this ore mix, slag volume is about 400 lb per ton of iron, but gravel has been added to produce a slag volume of about 600 lb and obtain iron of 0.035 to 0.040 pct sulfur.

The coke used is of excellent quality—physically and chemically—analyzing 7 pct ash and 0.70 pct sulfur, dry basis. Coke rate (2.5 pct moisture coke) has been about 1370 lb per net ton which means an effective carbon demand of about 1050 lb per net ton of iron. This is probably a reduction of about 16 pct in coke rate from that of a normal ore burden of average Lake Superior ores. Under the above conditions, daily iron production per furnace was about 1400 tons. Due to the high alumina-silica ratio in the Orinoco ore, the alumina content of the slag, even with the addition of gravel, has been high—17 to 18 pct—and dolomite is used as flux to give a like amount of magnesia in the slag. Such slag composition provides a satisfactory melting temperature and viscosity to promote desulfurization.

These 28-ft diam furnaces more recently have each averaged from 1880 to nearly 2000 net tons per day of iron production. A sintering plant will be erected to sinter the fines. It is expected that output will then be maintained at about 2000 net tons per furnace per day, and it is probable that the above coke rate can be maintained or bettered, due to better gas-solid contact.

Pellets From Taconite and Michigan Jasper Concentrates

Substantial quantities of pellets have recently been shipped and used in various furnace plants in the northeastern part of the country. Unfortunately no performance data have been published. Probably a million tons were shipped during 1955, and upwards of 3 million tons will be shipped in 1956 from various sources. The annual shipments are expected to reach about 18 million tons by 1960.

Joseph[5] suggests the following as the probable effect of pellets on blast furnace performance during the next few years: "As in all comparisons of raw materials, the improvement with pellets will depend upon the quantity of the ore they replace. Taconite pellets will contain about 62 to 64 pct iron compared with about 50 pct iron for the average Lake Superior iron ore. The substitution of pellets containing 63 pct iron, 9.0 pct silica and 0.7 pct alumina for one-half of the ore in a burden composed of 100 pct Lake Superior iron ore of average quality would reduce slag volume by about 200 lb per ton of iron. It is assumed that Lake Superior ore of average quality contains 50 pct iron, 10 pct silica, and 2 pct alumina. A coke saving of 80 to 100 lb per ton of iron may accordingly be expected from this reduction in slag volume. A further saving in coke may be expected from the better heat interchange with 50 pct of pellets of uniform size in the charge. Improved reducibility of pellets over the ore and more uniform gas flow through the charge will reduce solution loss. The combined coke savings due to better heat transfer and less solution loss should about equal the coke savings due to the reduction in slag volume. Therefore, total coke savings ranging from 160 to 200 lb, or from 10 to 12 pct, appear to be feasible when one-half of a 100 pct typical Lake ore burden is replaced with pellets containing 63 pct iron. Because most burdens contain some sinter or beneficiated material, the actual saving of coke may be somewhat less than this.

"Tonnages will increase for two principal reasons when pellets are substituted for Mesabi ore. A decrease in coke rate will automatically result in an increase in tonnage if the volume of blast remains constant. Secondly, the volume of blast can be increased because charges containing pellets will be more permeable to furnace gases. In brief, increases in daily tonnage ranging from 15 to 20 pct and reductions in coke rates ranging from 10 to 12 pct may be expected when pellets of good physical quality replace one-half of the ore in a burden of 100 pct Lake Superior iron ore of average quality."[5]

The alumina content of pellets is low. Joseph's analysis gives an alumina-silica ratio of only 0.08:1, while his average Lake Superior ore shows an alumina-silica ratio of 0.2:1. The ore burden of one-half pellets and one-half Lake Superior average ore would produce a slag rather low in alumina, about 11 pct alumina. Any increase in the proportion of pellets would further reduce the alumina in the slag.

Another possible ore burden would be one containing one-third Lake Superior ore, one-third pellets, and one-third Quebec-Labrador ore. Operation on such an ore burden, as compared to a 100 pct Lake Superior ore of average quality, should show a 10 pct reduction in coke rate and some 15 pct increase in production.

The use of Quebec-Labrador ore, with its fairly high ratio of alumina to silica, would offset the low alumina-silica ratio in pellets and help to maintain the alumina-silica ratio in slag close to that which has been general with average Lake Superior ore.

Table I. Blast Furnace Performance and Practice with Sized and Sintered Mesabi Iron Ores (From Dobscha[4] Table 5)

Data	Normal Ore Burden	Prepared Ore Burden	Difference Amount	Difference Pct
Production:				
Iron, net tons per day	1,324	1,605	+ 281	+ 21.2
Flue dust and sludge, lb per ton iron	284	227	— 57	— 20.1
Consumption:				
Net Coke, lb per ton iron	1,782	1,510	— 272	— 15.3
Effective carbon, lb per ton iron	1,180	1,002	— 178	— 15.1
Flux, lb per ton iron	1,007	677	— 330	— 32.8
Unrecovered metallics, pct	1.5	0.8	— 0.7	— 46.7
Slag:				
Ratio bases to acids	1.05	1.04		
Calculated volume, lb per ton iron	1,264	968	— 296	— 23.4
Practice:				
Air blown, std. cfm	83,604	85,651	+ 2047	+ 2.4
Blast pressure, psi	20	22	+ 2	+ 10.0
Blast pressure, °F	969	916	— 53	— 5.5
Top temperature, °F	356	323	— 33	— 9.3
Added water, lb per ton iron	151	92	— 59	— 39.1

Sinter

Dobscha stated:[4] "It has been generally recognized by blast-furnace men that physical preparation of the relatively fine Mesabi iron ores would be advantageous for furnace operation." The use of sintered iron-bearing materials has been increasing, and it would appear that such use will increase more rapidly during the next five years. A report published in 1944 by the AISI Technical Committee,[7] based on data collected from more than 30 furnace plants, showed that the trend of increasing production had nearly flattened out at about 9 pct increase

at 40 to 50 pct sinter." In 1940, "Slater" reported a gain of 9 pct in production and a drop of 5 pct in coke rate when increasing the sinter from 20 to 35 pct. On the other hand, he stated that attempts to charge 50 pct sinter and over were less successful."

More recently, due to the tests made by the U.S. Steel Corp., Dobscha[4] and Sundquist[5] have shown that increasing benefits of greater production and reduced coke rates can be obtained from sized ore and sinter and from 100 pct sinter.

Dobscha[4] in 1948 reported the results of a three month test on two identical furnaces, one of which used normal Mesabi ores, while the other was charged with a sized ore burden containing 20 pct of sinter. After one month operation, the burdens were reversed. One month was allowed for adjustments and was excluded. The test was concluded with two months operation with reversed burdens.

The sinter was prepared from the $-\frac{3}{8}$ in. Group 3 ore and represented about 65 pct of such ore. Group 3 ore, nominally $-6+\frac{3}{8}$ in. constituted 50.8 pct, and Mesabi Group 7 concentrates 29.2 pct of the ore charged. As only 20 pct sinter was used, it must have represented not quite one-fourth of the sinter produced from the total Group 3 ore. The improved furnace operation obtained must, therefore, be largely ascribed to the use of the large proportion of coarse ore, much in excess of the normal complement had all the sinter been charged.

The comparative results of this test are shown in Table I. Production was increased 21.2 pct, net coke rate was reduced by 15.3 pct, slag volume reduced by 23.4 pct, and casts of off-grade iron were materially reduced. A heat balance was presented which shows a saving of 14.2 pct in the heat required for the sized and sintered ore burden. Of this saving, about 44 pct came from the lower slag volume and about 41 pct from the lower heat demand for the dissociation of chemically combined water and the vaporization and dissociation of the total water in the burden containing sized and sintered Mesabi ore.

Furnace Operation on 100 Pct Sinter

Sundquist[5] reports the results of operation of a furnace at Gary Works on 100 pct sinter for six months during the winter of 1953–1954. The sinter plant mix consisted of 52.5 pct ore fines, 38 pct flue dust, and the remainder was scale and coke breeze. The average results obtained are shown in Table II together with the results obtained on No. 8 furnace, of identical design, and the average of all other basic furnaces at Gary Works on normal ore burden during the same period of six months.

Sundquist draws the following conclusions from these operations:[5]

1) It was not necessary to provide a long period of adjustment when changing the burden to include a high percentage of sinter.
2) There was practically no change in the temperature of the iron produced.
3) High blast temperatures were demanded for smooth operation.
4) Lower wind volumes were required.
5) There was a tendency to build up on the walls, requiring periodic cleaners.
6) There was a definite increase in iron production, lower coke rate, and lower flue dust production.
7) The thermal load of the furnace was significantly decreased.
8) When higher percentages of sinter are employed, it is extremely important to have close control of the sintering operation.

The improvements shown by Dobscha[4] with sized ore and about one-fourth the normal complement of sintered Mesabi fines, and those shown by Sundquist[5] with 100 pct sintered Mesabi ore are so nearly the same in values, that it probably is not far from the truth to assume that the operations obtainable with a full complement of sintered $-\frac{3}{8}$ in. fines would approximate an average of the two, i.e., production would be increased about 19 pct, and coke rate would be reduced about 17.5 pct.

Self-Fluxing Sinter

No use of self-fluxing sinter in the U.S. has been found, but the economic possibilities as developed in Sweden and reported by Danielsson[10] are of interest. At the Domnarfvet Iron & Steel Works a fully self-fluxing sinter has been used since 1943, all limestone being added in the sintering plant. Much experimentation has been required to develop a "sinter of high quality which is characterized by 1) a high degree of oxidation, 2) high mechanical strength, 3) high microporosity."[10]

Danielsson states, "Tigerschiold has published data on coke consumption for Domnarfvet furnaces, which show how this was lowered from about 2100 lb per net ton in 1934 to 1300 lb per net ton in 1948, mainly because of beneficiation of the raw materials. Since then, investigations and experiments have given a better understanding of the reactions going on in the furnace. By applying these experiences in design and operation of the furnaces, further improvements have been made, which have led to a coke consumption of about 1170 lb per net ton as a one-year average, and this figure does not seem to represent a minimum."

Table II. Summary of Blast Furnace Performance and Practice with 100 Pct Sinter and Normal Burdens (From Sundquist[5] Table 7)

	No. 12 Furnace 100 Pct Sinter	Normal Burdens		Difference of No. 12 Furnace to			
		No. 8 Furnace	All Basic Furnaces Except No. 12	No. 8 Furnace		All Basic Furnaces Except No. 12	
				Amount	Pct	Amount	Pct
Coke rate	1328	1655	1621	−327	−19.8	−293	−18.1
Effective carbon rate	1011	1256	1230	−245	−19.5	−219	−17.8
Production, tons per day per sq ft hearth area	2.74	2.37	2.30	+0.37	+15.6	+0.44	+19.1
Flue dust, avg. lb per ton	105	195	216	−90	−46.2	−111	−51.4
Yield, pct	99.3	90.4	91.4	+8.9	+9.8	+7.9	+8.6
Wind volume, cu ft per sq ft hearth area	136.66	145.59	140.12	−8.93	−6.1	−3.46	−2.5
Hot blast temperature, °F	1210	1018	1007	+192	+18.9	+203	+20.2
Slag volume	927	1168	1128	−241	−20.6	−201	−17.8

Nodules

An alternative process to sintering for agglomerating iron ore fines is nodulizing in a rotary kiln. This process has not been practiced extensively in this country on blast furnace ore burden materials.

Dobscha[11] reported the results of a four month comparative test on two identical furnaces during early 1945. This test was conducted in the same manner as described for the test with sized Mesabi ore and sinter, given earlier. The prepared ore burden consisted of 51.9 pct of coarse Group 3 ore, 21.3 pct of nodulized $-\frac{3}{8}$ in. Group 3 fine ore and 26.8 pct of Mesabi Group 7 concentrates. The nodules had been made in a cement kiln at a temperature below that necessary to produce good nodules and "naturally resulted in a higher percentage of fines in the product."[11]

The comparative results of this test are shown in Table III. The improvements obtained are not as great as shown in Table I for a variety of reasons which are brought out in the discussion of Dobscha's paper on sized ore and sinter.[6] They are simply included here to complete the record.

Probable Change in Iron Production and Coke Rates Due to Improved Iron-Bearing Raw Materials By 1960

By 1960 it is probable that the sources of the iron ore for the U. S. will be about as follows:[1]

	1,000 Gross Tons	Pct
Lake Superior Ores	63,000	45.3
Taconite and Michigan Concentrates (Pellets)	17,750	12.8
U. S.—N. E., Southern and Western	17,000	12.2
Imports—Net Canadian	20,300	14.6
—All Others	21,000	15.1
Total	139,050	100.0

The various combinations in which these raw materials may be used are infinite and the impact of the new ores and beneficiated materials will largely be felt in the northern steel producing regions. Therefore, in setting up the following schedule, the new raw materials are allocated to that area, although some may be used in the southern and western steel producing districts. It is believed this simplification will not introduce any appreciable error in arriving at the overall figures for the United States. It is also assumed that the ores originating in the northeastern, southern and western districts will be of substantially the same quality as in the past. Further, the improved performance of the Orinoco-Peruvian ore is assigned to only the increase in "Imports—All Others" beyond those of 1953. With these considerations, a probable allocation of the 1960 ores, given above, is shown in Table IV, which also shows their effect on the overall changes in iron production and coke rates for the United States.

Table III. Blast Furnace Performance and Practice with Sized and Nodulized Mesabi Iron Ores (From Dobscha[11] Table 5)

Data	Normal Ore Burden	Prepared Ore Burden	Difference Amount	Difference Pct
Production:				
Iron, net tons per day	1,400	1,591	+ 191	+ 13.6
Flue dust and sludge, lb per ton iron	237	215	— 22	— 9.3
Consumption:				
Net Coke, lb per ton iron	1,766	1,624	— 142	— 8.0
Effective carbon, lb per ton iron	1,181	1,085	— 96	— 8.1
Flux, lb per ton iron	790	632	— 158	— 20.0
Unrecovered metallics, pct	1.9	1.3	— 0.6	— 31.6
Slag:				
Ratio bases to acids	1.034	1.040		
Calculated volume, lb per ton iron	1,100	954	— 146	— 13.3
Practice:				
Air blown std cfm	86,976	88,768	+ 1792	+ 2.1
Blast pressure, psi	21	22	+ 1	+ 4.8
Blast temperature, °F	983	946	— 37	— 3.8
Top temperature, °F	320	316	— 4	— 1.3
Added water, lb per ton iron	174	137	— 37	— 27.0

Table IV indicates that by 1960 the effect of the new ores will be to reduce coke rates by 10 pct. The American Iron & Steel Institute reported that in 1953 the average coke rate for all furnaces, excluding furnaces making ferroalloys, was 1812.6 lb per net ton of iron. A 10 pct reduction in coke rate, due to iron-bearing raw materials, by 1960 would result in a coke rate of 1631 lb.

The new high-grade iron ores and beneficiated raw materials are going to materially reduce slag volumes, which will create difficulties in obtaining the desired control of sulphur in the hot metal. This will make the use of low-sulphur coking coals a matter of vital importance in attaining satisfactory quality hot metal.

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Table IV. Probable Utilization of the Iron Ores Available to Blast Furnaces in U. S. in 1960 and Their Effect on Iron Production and Coke Rate

Type of Ore Burden	U.S. Ore Supply, Pct	Iron Production Change, Pct	Iron Production Effect on U.S., Total	Coke Rate Change, Pct	Coke Rate Effect on U.S., Total
½ Lake Superior, ½ Pellets	18.7	+ 17.0	+ 3.18	—11.0	—2.06
½ Lake Superior, ½ Labrador	21.6	+ 12.0	+ 2.59	— 9.0	—1.94
1/3 Lake Superior, 1/3 Labrador, 1/3 Pellets	10.8	+ 15.0	+ 1.62	—10.0	—1.08
Extra Orinoco and Other Imports	7.2	+ 20.0	+ 1.44	—16.0	—1.15
Mesabi + ¼ in. Coarse Ore and — ⅜ in. Mesabi Sintered	21.6	+ 19.0	+ 4.10	—17.5	—3.78
Northeastern, Southeastern, and Western	12.2	0.0	0.00	0.0	0.00
Imports, 1953	7.9	0.0	0.00	0.0	0.00
Total	100.0	12.9	12.93	10.0	10.01

First-Hand Report On

Use of Basic Refractories In European Open Hearth Practice

by A. H. Sommer

Editors Note: The author, who participated in the Joint Metallurgical Tour in the summer of 1955, was asked to review his impressions of European open hearth refractory practice.

IN London, a representative from Bilston Works of Steward & Lloyds Ltd. read a paper on an all-basic furnace which has operated for a considerable period of time. This was the only time that furnace construction was discussed at the technical sessions. The author reported on three campaigns covering a period of more than four years with 1423 heats, 1107 heats, and 2205 heats per campaign. The general roof construction was of the regular European design with only the ribs being suspended and the valleys being sprung, p. 444. The total ingot production for the 2205 heat campaign was approximately 122,000 tons which is somewhat more than the 89,000 tons which Keystone reported last year for an all basic flat suspended roof. The heat size of this furnace is only 60 tons; however, the hot metal in the charge averaged approximately 60 pct. Operations were at the rate of approximately 9 ton per hr indicating a heat time of slightly less than 7 hr.

In Germany, by special arrangement, the writer was able to visit Mannesmann Hüttenwerke A. G., Duisburg-Huckingen, where two small shops are operated. In the No. 2 shop, which is new, the furnaces are 150-ton capacity and are at present equipped with silica roofs; however, the steel shop is arranged so that they can be converted to basic at any time. In No. 1 shop the older furnaces are of 85-ton capacity, and both silica and basic roofs are being used. They are getting as much as 400 heats on silica roofs and their best campaign to date on all basic construction is 1490 heats. Their furnaces likewise are suspended rib and sprung valley, or regular European type, on which they get 900 to 1000 heats before placing what they call repair blocks between the ribs over the valleys. The furnaces in this shop are operating with approximately 25 pct hot blown metal at the rate of approximately 11½ tons per hr indicating a heat time of slightly more than 7 hr. The total production on the 1490 heat campaign was approximately 127,000 tons or slightly better than the over-all production for the furnace at Bilston. In this shop they are also using complete basic ends and have extended basic brick over a portion of the checker chambers.

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The author compared notes with Dipl. Ing. K. Schermer of the Danish Rolling Mills in Frederiksvaerk, Denmark where they have in operation European-type basic roofs on three 115-ton capacity all-basic furnaces. One of their best campaigns ran 523 heats with a total production of 60,100 tons. This may look rather out of line compared to the operations in England and Germany; however, it is still a reasonable performance because the shop is operating with an all cold charge consisting of only 17 pct pig iron with the balance of the charge being steel scrap and some coke to supply the necessary additional carbon. The average tons per hr tap-to-tap in this shop is 10½ with a heat time of slightly less than 10 hr. The three basic furnaces in this shop have all been built since 1951, and besides being all basic including furnace ends, the entire checker chamber roof and 12 top courses of the checker work on one furnace are basic at the present time. The maximum firing rate in the Danish installation has been reported as approximately 70 million Btu per hr with an average rate of 57 million. The fuel is 100 pct oil.

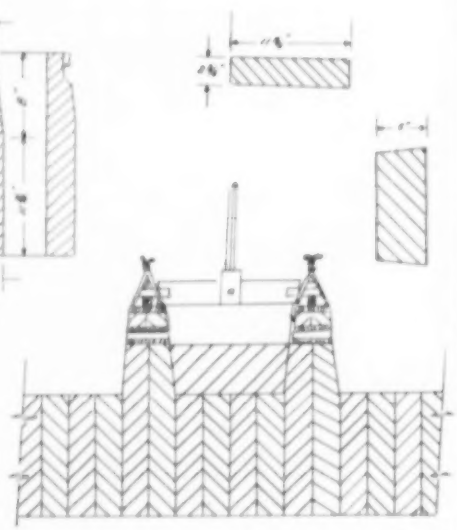
Brick Specifications

On the Continent, burnt chrome magnesite bricks are generally used. No chemically bonded bricks were installed for main roof construction until the latter part of 1955, but some chemically bonded bricks have been used in uptake and end construction for several years. In England, where the writer learned of only two other basic roofs being operated besides the Bilston installation, it seems that they are continuing to work with burnt magnesite chrome brick. The general information in regard to the English and German installations would indicate that somewhat better performance has been obtained in Europe with the all-basic main roof than has been obtained thus far in the U. S. The question of better brick should be left to the ceramic engineers; however, the writer is inclined to believe that some of the difference in performance might be due to carefully designed sprung type construction which includes rather high ribs.

OPEN HEARTHS IN EUROPE

Excluding England and Iron Curtain Countries

Country	Existing Furnaces	Silica Roofs	Basic Roofs	Slag Pockets & Fantails	Basic Checkers
Germany	199	107	92	21	25
France	124	107	17	2	8
Italy	64	54	10	6	—
Yugoslavia	24	—	24	2	—
Austria	24	2	22	17	5
Sweden	44	28	16	9	2
Belgium	18	16	2	—	—
Denmark	8	4	4	3	1
Finland	2	—	2	1	1
Greece	2	1	1	—	—
Holland	10	2	8	1	—
Saar	12	6	6	2	—
Turkey	6	2	4	1	1
Total	537	329	208	65	43



European Construction

European basic roof construction, as shown above, is only 40 pct suspended, consisting of the ribs, and the balance or 60 pct is sprung, forming what is termed valleys. The ribs consist of key shaped brick which are approximately 19¾ in. long and 2¾ in. thick with the top 8 in. being tapered on one side. These ribs are held up against a rather heavy "T" section which is bent to Save the same outside radius as the roof itself. They are held up against the T section by a heavy gauge wire which in some cases goes through a hole in the top of the brick, and in other cases the rib bricks are equipped with lugs under which the wire can be looped as shown in the top of figure to the left. The straight side of two rib bricks are set back to back so that a wedged shape area is formed above the valley courses to provide for the installation of a repair block approximately 5 in. thick and 11 in. wide just prior to the time the valley courses burn through. The valley courses are made up of four rings of key brick which are approximately 2¾ in. thick and 11¾ in. long.

General Use of Basic Refractories in Europe

It was possible to obtain a rather complete survey of existing open hearth furnaces of various types on the Continent, excluding those behind the Iron Curtain. For this survey, the author is indebted to Mr. Hans Steyrleightner and the Austrian-American Magnesite Co. Of particular interest is the use of basic refractories extended to include checkers and the present high percentage of basic roofs compared to silica roofs, particularly in Germany and Yugoslavia. A considerable number of furnaces in Europe are operating with silica in the ends of the furnace even though the roof is all-basic (in column 4 of the table only 65 furnaces have basic ends compared to 208 with basic roofs). Attention should be called to the fact that where basic checkers are indicated, only 50 pct or less of the entire checker volume is made of basic brick.

Dr. L. Hütter's *Basic Linings of Slag Pockets and Regenerator Chambers in Open Hearth Furnaces*, September 1951, has been reviewed several times, and was translated in 1953 by H. W. Henstchel. Permission to quote from his paper has been granted, to further outline the general trend towards the use of basic refractories in open hearth practice on the Continent:

> "In the light of present day construction technique, the evolution of the all-basic furnace proper (above floor level) may be considered completed, since its economy—with only very rare exceptions—is no longer in doubt.
>
> The longer campaigns made possible by the all-basic lining of the furnace proper led to a number of measures aimed at eliminating shut-downs caused by necessary repairs of the regenerative system, in other words, measures aimed at increasing the service life of the regenerative system."

Dr. Hütter indicates that the installation of basic ends in Europe was influenced somewhat by the success of basic ends in the U. S., although the prime reason for using basic brick in checkers was given as a means of balancing checker life with the main roof. He has the following to say in favor of basic checkers:

> "By increased heat storage capacity and better thermal conductivity of the basic checkers, the temperature variation during one cycle was decreased from 132°C using silica to 96°C using basic refractories.
>
> The refractoriness of basic-checkers offers the possibility to work with higher regenerator temperatures. The higher air-exit temperature achieved by changing from silica to basic resulted in a decrease of the heat requirement per ton of steel from 1.25 million k cal to 1.20 million k cal per ton of steel. This considerable decrease of heat requirement is an important figure on the credit side in favor of the economy of the basic-checker versus the silica checker used before."

Conclusion

Based on limited experience in the U.S. and information available from Europe, this writer believes it can now be concluded that the all-basic roof which results in a higher firing rate will definitely require a more extended use of basic refractories throughout the entire regenerative portion of the furnace if maximum furnace life and economy are to be expected.

Fabrication of Thorium Powders

Consolidation of hydride process, electrolytic, calcium reduced, and comminuted thorium powder, as well as saw chips and lathe turnings, by vacuum hot pressing and by cold pressing-vacuum sintering was studied. The mechanical properties of the consolidated material in the extruded form are compared with those of wrought castings.

by W. W. Beaver, K. G. Wikle, and J. G. Klein

AT present there is little industrial use for thorium metal, although it has some important though small scale applications in electronic equipment. Despite its high melting point—about 1750°C—a low modulus of elasticity, 11.4×10^6 psi at 20°C;[1] relatively low mechanical properties coupled with a high density, 11.7 g per cu cm; and an unusually high chemical activity with normal atmospheres limit any structural applications.

The metal is utilized as an alloying element principally in magnesium. Pure thorium finds utility as electrodes in gaseous discharge lamps such as the high intensity mercury lamp[2] because its low work function and high electron emissivity provide lower starting potentials and more uniform operating characteristics than other available materials. The metal is also found in photoelectric tubes used for the measurement of the ultraviolet spectrum.[3] Thorium metal has been used in germicidal lamps of the cold cathode type as sputtered coatings on nickel in order to provide a low work function surface and a low starting voltage. Other applications have involved the radioactive properties of thorium for the production of ionized particles.[4]

The potential value of thorium is much greater than its present use pattern because of possible utility in the field of nuclear power. Th_{232} may be converted through nuclear reaction to a fissionable element U_{233} which should be capable of acting similarly to U_{235} in the generation of atomic power. Thorium has been reported to be about three times as plentiful as uranium in the earth's crust, placing it in the order of abundance of lead and molybdenum.[5] Thus, it is of interest in augmenting the potential supply of fissionable material for nuclear power.

Because of its high melting point, thorium is usually produced as a powder through the calcium reduction of its oxide or thermal reduction of halides by sodium, magnesium, and calcium. It may also be produced in flake form by electrolysis of fused alkali or alkaline earth chlorides and fluorides. Therefore, powder metallurgy assumes importance in the fabrication of thorium metal shapes. Furthermore, it is rather difficult to obtain pure thorium by melting, as the molten metal reacts readily with graphite as well as oxide, carbide, and nitride refractories. These contaminate the melt with oxides, carbides, and metallic impurities.[6]

The current investigation was undertaken to examine the fabrication of thorium by powder metallurgy methods which have been used for the commercial production of beryllium and other metals.[7] A sparcity of data concerning the comparative cold and hot compaction of thorium powders of different derivation existed. Therefore, all commercially available types were examined along with other experimentally produced thorium powders in order to round out the comparison of consolidated thorium powders with melted reguline metal.

Review of the Literature

By heating a mixture of ThCl, with potassium, Berzelius[8] made the first thorium metal as an impure powder in 1828. Improvements in the basic process, increasing thorium assay to 99 pct, were made by several investigators including Arsem,[9] Lely and Hamberger,[10] and Von Bolton.[11]

Calcium reduction of ThO_2 to make powders was investigated by Berger,[12] Huppertz,[13], Kroll,[14] and Kuzel and Wedekind.[15] A thorium powder produced by this method using a $CaCl_2$ fluxing agent assayed 99.7 pct, as reported by Marden and Rentschler.[16] Compacted and sintered, this product was found to be ductile, and could be fabricated into wire and sheet. Improvements of the calcium reduction process were made later[17] wherein $CaCl_2$ was eliminated from the reaction, producing metal assaying 99.8 pct Th. Further work by Lilliendahl[18] showed that a coarser metal could be obtained by the substitution of ThCl, or $ThOCl_2$ for oxide with consequent advantage of stability to atmospheric reaction.

Reports on the technology of thorium developed in Germany during World War II have been made by Espe.[19] Thorium powder of 99.5 pct Th was obtained by reduction of the oxide by calcium. Screening to −200 mesh, compacting with about 20 tsi, and sintering in vacuo at 1320° to 1360°C for 3 hr resulted in a porous sinter cake. The sinter cake was sufficiently ductile to be worked into bar, wire, and sheet which could be employed as electrode materials.

W. W. BEAVER, Member AIME, K. G. WIKLE, Associate Member AIME, and J. G. KLEIN are associated with The Brush Beryllium Co., Cleveland.

TP 4086E. Manuscript, Apr. 11, 1955. Philadelphia Meeting, October 1955.

The Transactions papers appearing in the Journal of Metals during 1956 will subsequently appear in AIME Transactions Volume 206, and may be permanently referenced to that volume.

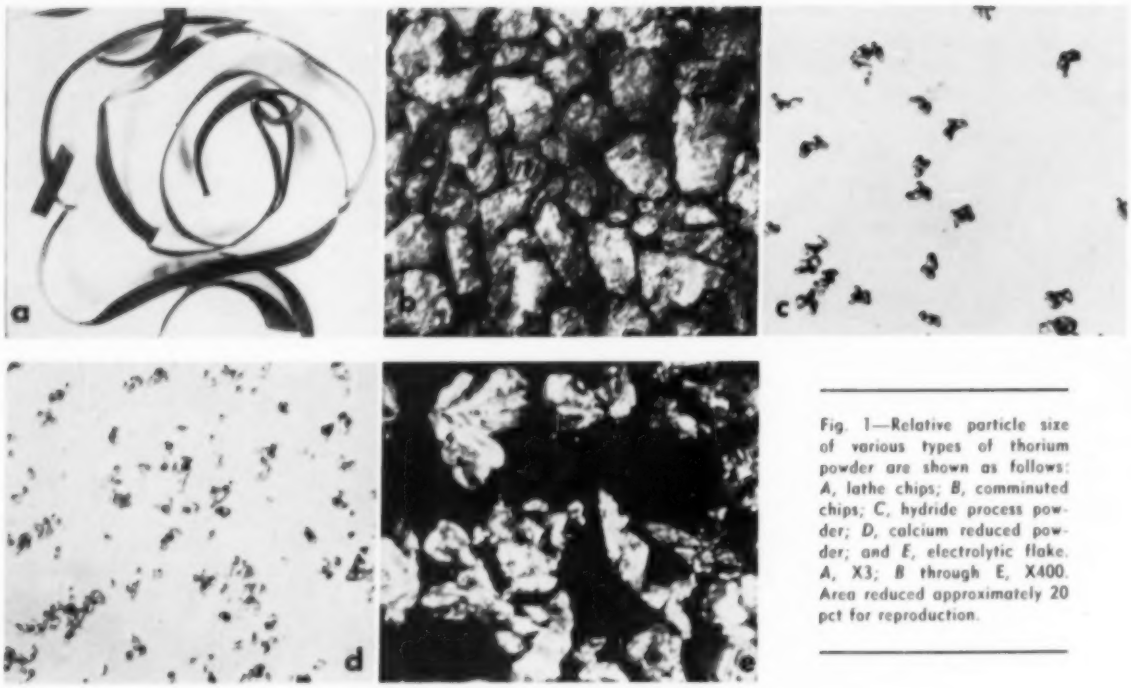


Fig. 1—Relative particle size of various types of thorium powder are shown as follows: *A*, lathe chips; *B*, comminuted chips; *C*, hydride process powder; *D*, calcium reduced powder; and *E*, electrolytic flake. *A*, X3; *B* through *E*, X400. Area reduced approximately 20 pct for reproduction.

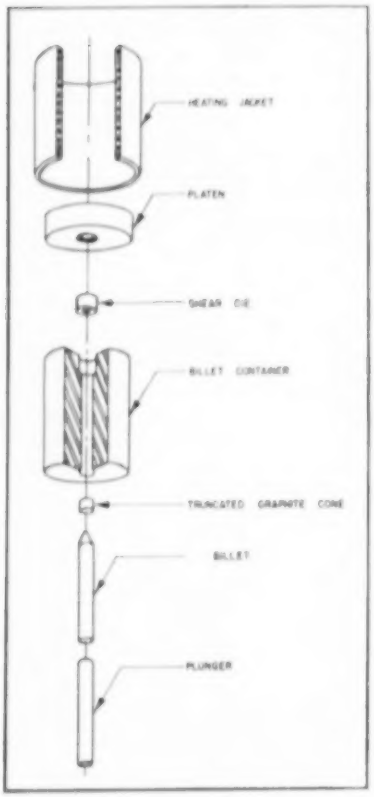


Fig. 2—Diagram shows exploded view of warm extrusion assembly.

The production of thorium powder by electrolysis of molten salts of halides was first reported by Moissan and Honigschmidt,[20] as well as by Von Wartenberg.[21] These investigators deposited flake of about 88 pct Th out of a fused mixture of $ThCl_4$, NaCl, and KCl. Higher assay metal was obtained by Driggs and Lilliendahl,[22] whose electrolyte was a mixture of equal parts of NaCl and KCl with the double fluoride $ThF_4 \cdot KF$. A thorium powder-salt mixture was deposited on a molybdenum cathode as it was slowly raised from the electrolyte.

Additional methods of producing thorium powders reported in the literature are by the hydriding of metallic thorium chips or turnings[23] and by formation of thorium crystals through thermal dissociation of ThI, on a heated wire.[24] Little information has been published on fabrication of thorium by powder metallurgy, although Lilliendahl has reported some data on cold pressing and sintering.[22] In his reference, thorium powder produced by the calcium reduction of ThO_2 was pressed in lubricated hardened steel dies at 20 to 50 tsi. To avoid seizing of the powder on the dies under axial pressing, the thorium is enclosed in a rubber tube hermetically sealed, and pressures of about 10 to 15 tsi applied. Sintering of these compacts was carried out under vacuum, 1×10^{-4} mm Hg or better at 1200°C or higher. It was stated that if the compacts were degassed in vacuo at 1000°C, the final sintering at 1300°C could be performed in argon or helium gas to obtain sintered densities of 11.3 to 11.4 g per cu cm, with an increase of ThO_2 of not more than 0.2 pct over that of the powder.

Materials and Procedure

Materials—A number of materials were investigated in this work. These include the following: thorium castings, saw chips and lathe turnings, powder attritioned from turnings, powder made by experimental hydriding turnings, commercial thorium powder made by the hydride process, commercial thorium powder made by reduction of ThO_2 by calcium, and electrolytic thorium flake.

Major contaminating elements are shown in Table I. In some cases, the analytical data is presented as

Table I. Variation of Chemical Impurities in Various Types of Thorium*

Element	Casting	Impurity		Attritioned Powder	Experimental Hydrided Powder	Commercial Hydrided Powder	Calcium Reduced Powder	Electrolytic Flake
		Saw Chips	Lathe Chips					
Th	99+	99+	99+	99+	98+	95-96	99.7	98+
Ca	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01
Be	<0.02	<0.02	<0.02	<0.02	<0.02	<0.01	<0.01	<0.01
Fe	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.05
C	<0.05	<0.05	<0.15	<0.15	<0.15	<0.10	<0.02	<0.20
ThO_2	1.11	1.30	1.15	1.62	1.97	1.24	0.23	0.15

* All other elements analyzed for less than 0.01 pct, except nitrogen, which averaged less than 0.02 pct.

representative of type rather than an actual analysis of material used for this investigation. The major impurity, ThO_2, was analyzed for each type of powder, however.

Material Preparation:

1) Cast Thorium—Thorium castings with a 3 in. diam were extruded to 1.4 in. diam at about 550°C, preheat temperature. To provide ½ in. diam x 1.5 in. long stock for tensile testing, the 1.4 in. diam rod was re-extruded to ⅝ in. diam.

2) Chips and Turnings—Saw chips were made by cutting cast material with power hack saws. The screen analysis in Table II indicates that this material consists mostly of particles in the size range of −20 +80 mesh. Thorium machines similarly to low carbon steels. Lathe turnings were produced with a high speed steel tool as rough cuts. The lathe operation was carried out without cutting fluid to keep the turnings as clean as possible. However, some carbon and oxygen increases were noted above the cast raw material analysis after subsequent comminution.

Before the chips and turnings were compacted or attritioned into powder, they were cleaned to remove oil and surface contamination. This cleaning operation was performed by first degreasing with CCl_4 and then leaching in a nitric acid-sodium silicofluoride solution containing one part 70 pct HNO_3, three parts water, and 0.003 mol sodium silicofluoride. The chips were allowed to remain in this cleaning bath for about 5 min, after which they were rinsed in alcohol or acetone to facilitate drying. No appreciable loss of metal was noted unless the pieces were especially small and the temperature of the cleaning solution was allowed to exceed 40° to 50°C.

3) Powder by Hydride Process—In making thorium powder by the hydride process, cleaned lathe chips were used as feed material. In this method, ThH_4 is produced at between 250° and 285°C and is decomposed to the dihydride at 500°C. Finally, the dihydride is decomposed at 700°C with the formation of thorium powder. A detailed description of the thorium hydride process has been given by Chiotti and Rogers.[8]

A charge of thorium lathe turnings converted to powder by the hydride process showed a particle size range of 60 pct −35 mesh, with the balance +35 mesh. The characteristics of −35 mesh and finer powder fractions are listed in Tables II and III. It can be seen that unless reprocessing or milling is resorted to, the hydriding treatment produces relatively coarse powder from turnings and chips. However, this material can be handled with ease, as it exhibits a high apparent density and good flowability.

4) Attritioned Powder—Attritioned powder was made by pulverizing cleaned thorium chips and lathe turnings with a small laboratory Wiley mill. Because of the pyrophoric nature of finely divided thorium, the attritioning had to be performed in a dry box from which the air had been evacuated and replaced by purified helium of about −60°C dew point. Because of the soft, ductile nature of thorium, the grinding was somewhat difficult, but by no means unfeasible. As can be seen in Table II, the attritioned powder was coarse, running mostly +100 mesh. Its apparent density and flowability were relatively good, although some oxide increase was found even though comminution was carried out in a dry inert atmosphere, Table I.

5) Commercial Hydride Powder—Commercial powder produced by the hydride method was obtained from Metal Hydrides Inc. Its particle size was small, which should be satisfactory for pressing green compacts and sintering. However, the assay

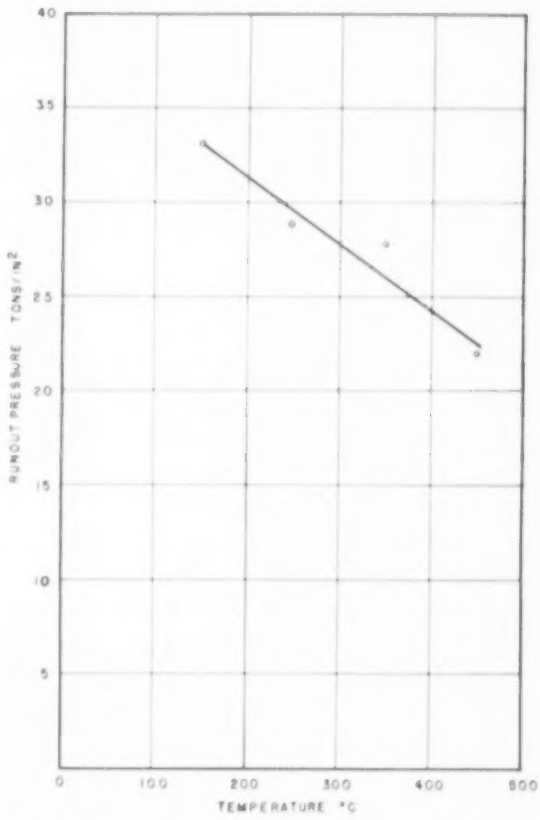


Fig. 3—Effect of temperature upon runout pressure in the warm extrusion of thorium is plotted. A reduction ratio of 4:1 was used with ¾ in. diam billets.

Table II. Particle Size Variations in Thorium Powders

Powder	Average Diameter, μ, Fisher Sub Sieve Sizer	Mesh Fractions, Pct										
		−10 +20	+35	+60	+80	+100	+150	+200	−200	−200 +250	−250 +325	−325
Raw Chips	—	0.3	35.1	28.4	16.7	8.2	5.7	3.3	2.3	0.5	1.3	0.5
Attritioned from Chips												
−35 Mesh	—	—	—	42.6	—	23.6	10.3	8.2	15.3	—	—	—
−60 Mesh	—	—	—	—	—	43.2	17.5	13.1	26.2	—	—	—
Commercial Hydrided Powder	5.7	—	—	—	—	—	—	—	—	—	—	100.0
Calcium Reduced Powder	4.7	—	—	—	—	—	—	—	—	—	—	100.0
Experimental Hydrided Powder												
−35 Mesh	—	—	—	20.3	28.1	18.5	15.6	10.6	6.9	1.6	3.0	2.3
−60 Mesh	—	—	—	—	35.3	23.2	19.6	13.3	8.7	2.0	3.8	2.9
−100 Mesh	—	—	—	—	—	—	47.3	32.0	20.7	4.7	9.1	6.9
−200 Mesh	—	—	—	—	—	—	—	—	—	22.8	43.9	33.3
−250 Mesh	—	—	—	—	—	—	—	—	—	—	56.8	43.2
Electrolytic Flake												
−35 Mesh	—	—	—	26.2	—	36.5	13.6	11.3	12.5	—	—	—
−60 Mesh	—	—	—	—	—	29.9	24.8	22.7	22.7	—	—	—

was low. The apparent density of this powder was high, 4.27 g per cu cm, but flowability was poor, probably because of the fine particle size.

6) Calcium-Reduced Powder—Thorium powder produced by the reduction of ThO_2 with calcium was supplied by the Westinghouse Electric Corp. The particle size of this material was quite fine, 4.7 μ. Its assay was very high, but its apparent density was very low. The powder would not flow.

7) Electrolytic Flake—The thorium used was an experimental lot produced by the deposition of flake out of a molten salt mixture. This flake was obtained from Horizons Inc. The particle size is coarse, being quite similar in distribution to the attritioned powder. Like the attritioned powder, the flake has good flowability.

Five of the powders described are shown, with their relative sizes and shapes, in Fig. 1.

Processing Technique—*Cold Pressing:* Green compacts were made of the various thorium powders by pressing in oil dag-coated, hardened steel dies. Compacts of from ¾ in. to 2½ in. diam were made without internal lubricants.

Vacuum Hot Pressing: Vacuum hot pressing can be carried out up to 1100°C in commercial furnaces heated by natural gas or standard resistance wire. Therefore, the hot pressing tests were carried out in graphite dies at this temperature to simulate operation under production conditions. Even though a low temperature was used, it was possible to consolidate the thorium powders close to maximum density of 11.59 g per cu cm—density of cast thorium containing same impurities—by hot pressing for a period of from 2 to 4 hr with 1200 psi in a vacuum, 30 μ. No reaction with the graphite dies was noted.

Sintering: Preliminary sintering tests with cold pressed compacts indicated that consolidation starts at about 1100° to 1150°C, increasing to a maximum at 1350° to 1400°C. Additional heating up to 1570°C showed little further densification. Consequently, a temperature of 1400°C was selected for sintering, which was carried out in an induction heated, quartz vacuum chamber under 50 μ.

Extrusion: After the cold pressed compacts were sintered or vacuum hot pressed, they were machined to extrusion billets. As can be seen in Fig. 2, extrusion billets had a leading end in the shape of a truncated cone, with an included angle of 60° to 90°. The extrusion tool assembly was made of 18-4-1 type high speed steel, heat treated to about Rc 60

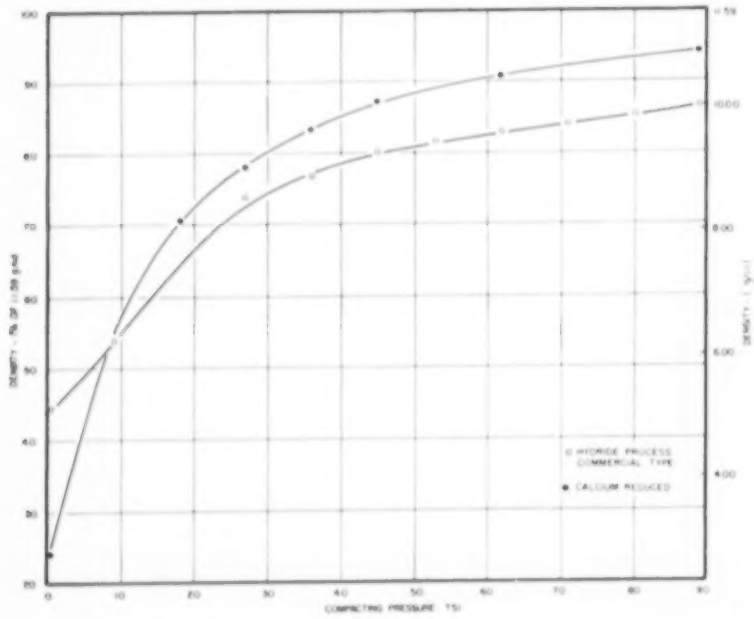


Fig. 4—Compactibility of commercial thorium powders is plotted.

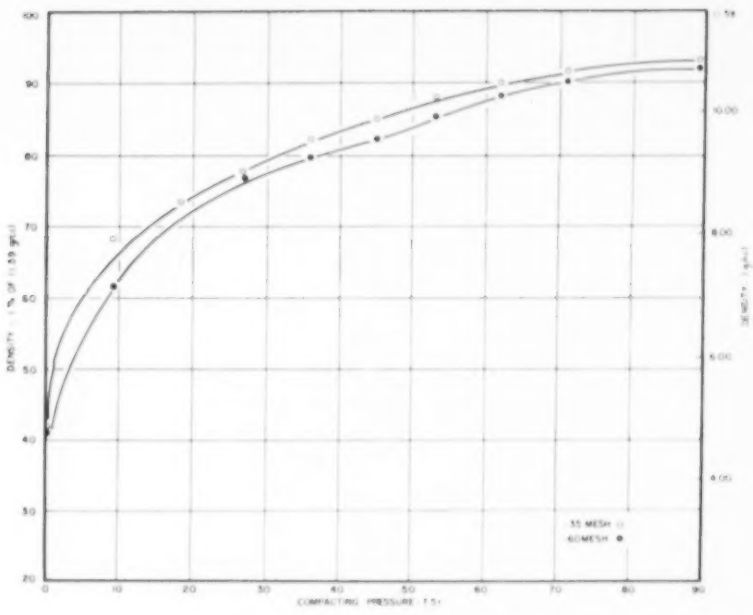


Fig. 5—Compactibility of thorium powder comminuted from machine chips is plotted.

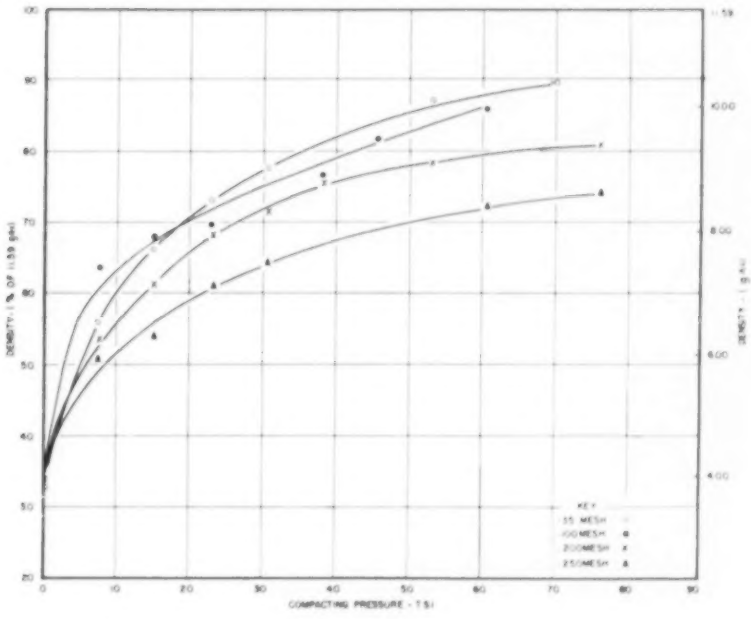


Fig. 6—Compactibility of experimental hydride process thorium powder is plotted.

hardness. Extrusion was carried out to bring the sintered powders to full density and to make their properties comparable to cast and wrought thorium.

The extrusion operation was performed in the temperature range 400° to 550°C. Lubrication on the billets consisted of a coating of oil dag, MoS_2, or a mixture of the two. A graphite cone was used to fit around the leading end of the extrusion billet. This was crushed with the initial application of pressure, causing a low friction taper to form at the entrance to the shear die. The pressures required to extrude thorium at 425°C ranged from 20 to 75 tsi, and depended upon the reduction ratio, quality of lubrication, and included angle of the truncated cone. It appears that with a 0.003 in. coating of oil dag, a 60° included angle, and a 4:1 reduction ratio, a pressure of about 40 tsi would be necessary to start the extrusion, after which the pressure drops off to about 25 tsi. Data on extruding cast and rolled thorium at various temperatures are presented in Fig. 3 to indicate how thorium extrudes by the technique used in this work. The curve in the figure shows a steady drop in the runout extrusion pressure—relatively constant pressure period after extrusion has

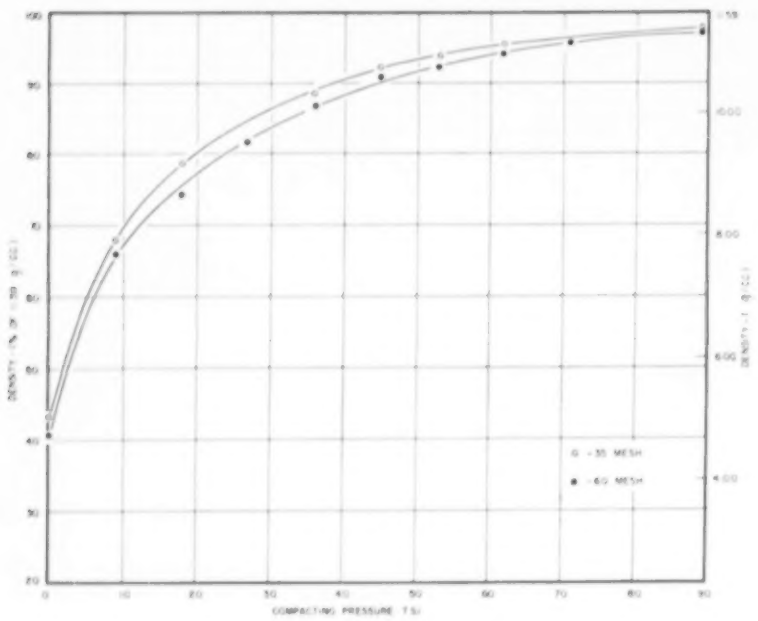


Fig. 7—Compactibility of electrolytic thorium powder is plotted.

started—with increasing temperature, employing a reduction ratio of 4:1.

Tensile Testing: All material under investigation was tested, using a small button head type of tensile specimen with a diameter of 0.15 in. and a gage length of 0.6 in. The apparatus and testing procedure for this type of test bar has been previously described in detail.[7] The small sample was chosen for the comparison tensile test because of the small amount of material available from various experimental lots of thorium.

Some of the sintered or hot pressed material was tensile tested in the as-extruded condition, while other tests were made after vacuum annealing for 1 hr at 650° to 800°C.

Metallographic Examination: Metallographic samples were prepared by wet grinding with 150 through 400 grit Carborundum papers, rough polishing with levigated alumina on Metcloth, and final polishing with AB Metpolish No. 3 on microcloth. Electroetching was employed with 25 pct HNO_3 in aqueous solution, using a 2 amp current.

Analysis of Thorium Oxide: A 1 g sample of powder was dissolved in 300 cu cm of a 1:1 mixture of HCl and H_2O after bubbling nitrogen through the solution to remove dissolved oxygen. The acid was added cautiously until the reaction ceased, and the sample mixture boiled for 4 hr with acid added as needed. The solution was then filtered through No. 42 paper and washed with a 1:9 mixture of HCl in H_2O. After ignition at 1000°C, the residue was weighed as ThO_2.

Experimental Results

Cold Pressing—Compaction curves for the thorium powders considered in this investigation are shown in Figs. 4 to 7. The comparative consolidation of the various powders at 40 tsi is listed in Table IV. At this as well as at higher compaction pressures, the coarser fractions of any thorium powder exhibit better compactability than the finer fractions. For the same mesh fraction, the electrolytic flake showed better compactability than attritioned chips or decomposed hydride powder. The most compactable of the fine powders was calcium reduced metal. As might be expected from its coarse particle size and the excellent ductility of thorium, scrap consisting of saw or lathe chips had the best over-all cold compactability of all the metal tested.

Hot Pressing—The densities of the various vacuum hot pressed thorium powders are shown in Table IV. In any given type of powder, the fine fractions hot pressed better than corresponding coarser fractions, reversing the effects observed for cold pressing. Despite this trend, the coarse lathe turnings hot pressed to 98 pct + of 11.59 g per cu cm, the density of cast metal corrected for impurities.

Under conditions of vacuum hot pressing, 25 to 50 μ, the thorium oxide content increased from 1.15 to 1.45 pct or about 350 ppm O, again decreasing the maximum apparent density slightly. Oxidation of the finer powders during hot pressing was greater than that for any corresponding coarse fraction. The −60 mesh fractions of comminuted chips and electrolytic flake increased about 2000 ppm O_2. The powder made by decomposition of the hydride

Table III. Some Properties of Various Types of Powdered Thorium

Powder	Apparent Density, G per Cu Cm	Flow Rate, Hall, G per Min
Experimentally Produced Hydride		
−35 Mesh	4.19	Not measured, but similar to attritioned and electrolytic powder
−60 Mesh	4.33	
Attritioned Powder		
−35 Mesh	4.27	104
−60 Mesh	4.46	152
Electrolytic Flake		
−35 Mesh	3.95	131
−60 Mesh	4.01	144
Commercial Hydride Powder 5.7 μ Diam	4.27	None
Calcium Reduced Powder 4.7 μ Diam	2.23	None

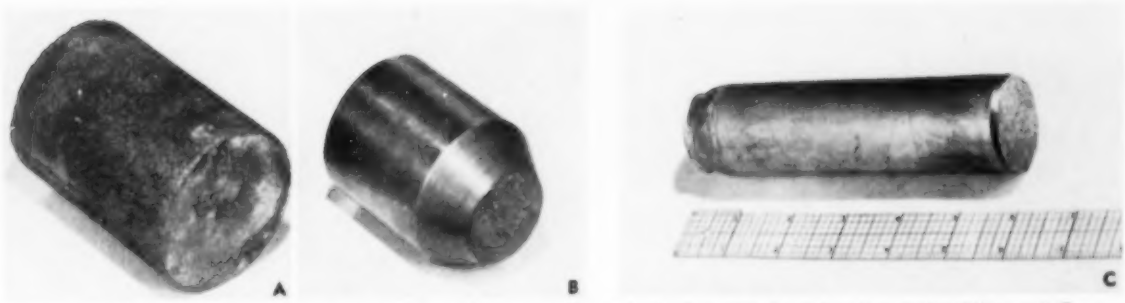


Fig. 8—Photographs shows fabrication of rod from thorium powder. *A* is the hot pressed powder; *B*, extrusion billet; and *C*, warm extruded rod.

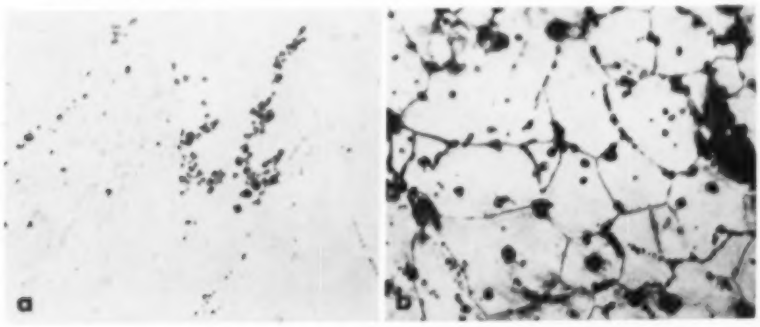
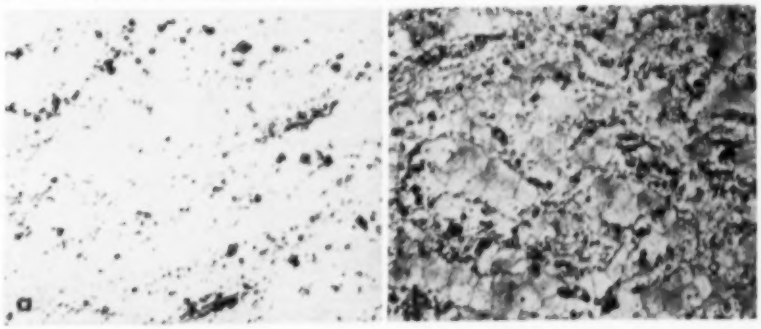


Fig. 9—Micrographs show vacuum hot pressed lathe chips. *A*, as-polished; *B*, electroetched. X250. Area reduced approximately 25 pct for reproduction.

Fig. 10—Micrographs show vacuum hot pressed attritioned lathe chips, —35 mesh. *A*, as-polished; *B*, electroetched. X250. Area reduced approximately 25 pct for reproduction.



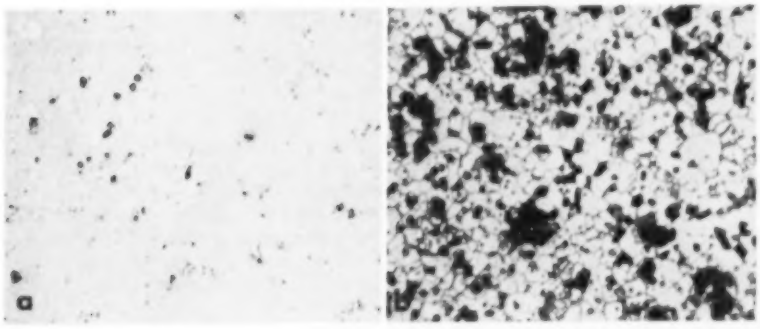


Fig. 11—Micrographs show vacuum hot pressed calcium reduced powder. *A*, as-polished; *B*, electroetched. X250. Area reduced approximately 25 pct for reproduction.

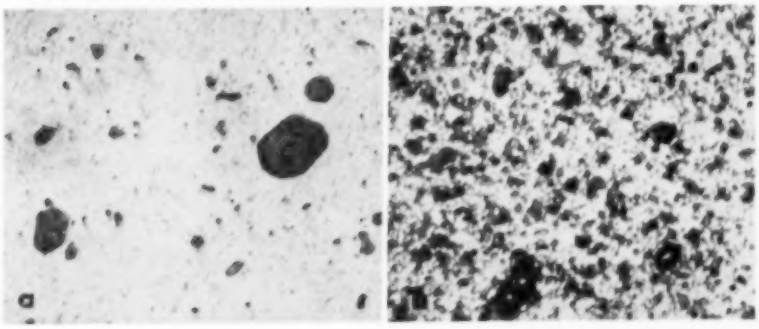


Fig. 12—Micrographs show cast, hot rolled, *warm* extruded thorium rod. *A*, as-polished; *B*, electroetched. X250. Area reduced approximately 25 pct for reproduction.

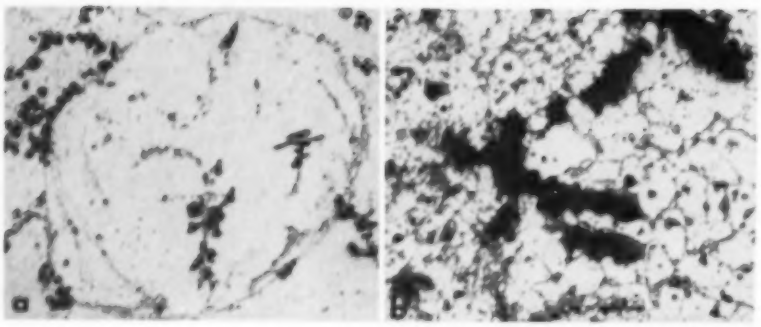


Fig. 13—Micrographs show vacuum hot pressed hydrided powder, —35 mesh. *A*, as-polished; *B*, electroetched. X250. Area reduced approximately 25 pct for reproduction.

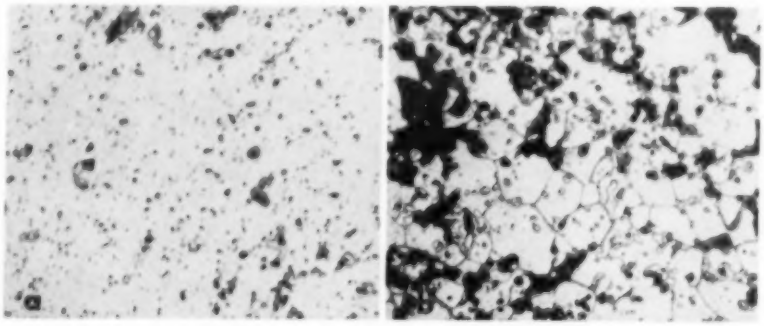


Fig. 14—Micrographs show vacuum hot pressed electrolytic flake, —35 mesh. *A*, as-polished; *B*, electroetched. X250. Area reduced approximately 25 pct for reproduction.

showed a gain of 1000 ppm for the same fraction under the same conditions of processing, possibly the effect of some protection from residual hydrogen. The calcium reduced powder of a considerably finer size showed a relatively low oxygen pickup of about 2000 ppm.

Lathe turnings, attritioned chips, experimental hydride powder, and electrolytic flake were all hot pressed to 98 to 100 pct of maximum density—probably even higher if the higher oxide content of the compressed powders is considered.

Table IV. Densities of Thorium Powders Consolidated by Several Techniques

	Density of Cold Pressed Material, 40 Tsi		Density of Cold Pressed and Vacuum Sintered Material, 1400°C		Density of Vacuum Hot Pressed Material, 1100°C, 1200 Psi	
	G per Cu Cm	Pct of 11.59 G per Cu Cm	G per Cu Cm	Pct of 11.59 G per Cu Cm	G per Cu Cm	Pct of 11.59 G per Cu Cm
Lathe Turnings	—	—	—	—	11.38	98.2
Saw Chips						
—20 Mesh	10.7	93	11.22	96.8	11.02	98.1
Comminuted Lathe Turnings						
—35 Mesh	9.7	84	10.06*	86.8*	11.32	97.7
—60 Mesh	9.5	82	11.17	96.4	11.38	98.2
Experimental Hydride Process Powder						
—35 Mesh	—	—	—	—	11.59	100.0
—60 Mesh	8.9	78	11.20	96.6	—	—
—100 Mesh	8.5	73	11.43	98.8	—	—
—200 Mesh	8.3	72	10.64	91.8	—	—
—250 Mesh	7.9	68	—	—	—	—
Electrolytic Powder						
—35 Mesh	10.5	91	11.21	96.7	11.20	96.7
—60 Mesh	10.3	89	11.39	98.3	11.39	98.3
Commercial Hydride Process Powder						
5.7 μ	9.0	78	10.23	88.3	11.03	95.2
Calcium Reduced Powder						
4.7 μ	10.0	86	10.37	89.5	11.34	97.8

* Blistered during sintering.

Sintering—The densification of cold pressed thorium powders by sintering at 1400°C in vacuo is shown in Table IV. As in hot pressing, the densification was greater for the finer meshed portions of the various powders than for coarse mesh fractions. Sintering at 1400°C gave densities not quite as great as hot pressing at 1100°C. Only —60 mesh electrolytic flake achieved densities greater than 98 pct of maximum density. Most of the sintering took place from 1200° to 1400°C, although one sample of —60 mesh experimental hydrided powder cold pressed at 70 tsi did densify 100 pct when sintering at 1570°C. Generally, densification was quite erratic above 1400°C, showing little advantage for increased temperature for most powders. Higher cold compacting pressures had little effect in increasing sintered densities except at sintering temperatures below 1400°C and on coarse particles which densified cold to 95 pct or greater of maximum thorium density. Vacuum sintered samples exhibited increases in oxide content similar to those found in hot pressing operations.

Mechanical Working of Thorium Powder Metallurgy Compacts—Extrusion at low temperature using reduction ratios as low as 2:1 densified most of the sintered and hot pressed compacts to maximum density, even when the billet density was only 90 pct of maximum. The commercial hydrided powder was the only type which could not be extruded. All others were extruded into ½ to ⅝ in. diam rods for comparative evaluation of mechanical properties in tension. A fabrication sequence for hot pressing and extrusion is shown in Fig. 8.

Sintered or hot pressed thorium compacts from 90 to 98 pct of maximum density were completely densified by coining and extrusion at 400° to 500°C in air without noticeable oxidation if starting billet oxide contents were below 5 pct ThO_2.

Evaluation of Densified Compacts—Tensile properties are given in Table V. All compacts were warm extruded and annealed to give an effective comparison. Tensile strengths greater than those

Table V. Tensile Properties of Consolidated Thorium Powders

Source	Fabrication*	Heat Treatment	Ultimate Tensile Strength, 1000 Psi	Yield Strength, 1000 Psi	Elongation, Pct	Pct, Cont.	Hardness, Rr
Cast, Virgin†	Ex	None	61.7	60.3	15.8	47.1	92.6
Cast, Virgin	Ex	1 hr at 660°C	41.8	34.1	38.6	64.8	68.1
Lathe Turnings	Vhp	None	43.8	36.8	5.2	8.5	76.8
	Vhp and Ex	None	57.7	54.2	11.0	23.2	93.1
	Vhp and Ex	1 hr at 800°C	47.3	36.4	22.5	26.8	85.5
Saw Chips	Vhp and Ex	None	49.2	48.0	1.0	1.1	92.6
−20 Mesh	Vhp and Ex	1 hr at 660°C	32.7	27.2	11.0	5.5	73.8
Attritioned Chips							
−35 Mesh	Vhp and Ex	1 hr at 800°C	51.4	49.6	4.9	6.7	87.2
−60 Mesh	Vhp and Ex	1 hr at 800°C	56.7	44.8	5.5	5.4	94.4
−35 Mesh	Cp-S and Ex	1 hr at 800°C	32.0	31.8	1.4	0.3	83.4
Electrolytic Flake							
−35 Mesh	Vhp and Ex	1 hr at 800°C	25.9	17.3	13.6	11.1	47.8
−60 Mesh	Vhp and Ex	1 hr at 800°C	22.8	19.8	10.2	11.7	46.7
−35 Mesh	Cp-S and Ex	1 hr at 800°C	18.0	15.4	6.6	4.4	52.2
−60 Mesh	Cp-S and Ex	1 hr at 800°C	25.7	17.6	16.6	18.3	43.9
Experimental Hydrided Powder							
−35 Mesh	Vhp	None	45.9	36.1	3.0	3.1	89.7
−35 Mesh	Vhp and Ex	None	67.7	66.1	2.1	1.5	96.8
−35 Mesh	Vhp and Ex	1 hr at 660°C	49.6	38.4	13.5	11.6	89.2
−35 Mesh	Vhp and Ex	1 hr at 800°C	48.7	38.2	14.0	14.7	86.8
−60 Mesh	Cp-S and Ex	None	62.2	60.2	6.7	7.2	90.6
−60 Mesh	Cp-S and Ex	1 hr at 660°C	48.9	41.3	11.4	16.7	82.0
−60 Mesh	Cp-S at 1570° and Ex	None	82.2	75.6	2.0	2.3	(>100 Rr = 75 Ra) 86.3 Ra
−100 Mesh	Cp-S and Ex	1 hr at 660°C	30.1	26.7	8.5	10.0	68.5
Calcium Reduced	Vhp and Ex	1 hr at 800°C	42.6	—	20.2	18.2	79.2

* Vhp stands for vacuum hot pressed at 1100°C; Cp-S, cold pressed at 89 tsi and sintered at 1400°C; and Ex, extruded with from 2:1 to 4:1 reduction ratio at 425°C.
† Recycle cast metal trends toward powder metallurgy values.

of cast metal could be developed, especially for consolidated fine powders, possibly because of the finer grain size and greater oxide content. The tensile elongations are somewhat lower for powder metallurgy compacts than cast metal, but not excessively. The uniform and rather high hardnesses probably reflect the relatively high and uniform oxide content of the powder compacts also.

Micrographs of the various compacted powders are shown in Figs. 9 to 14. The presence of oxides at the grain boundaries is indicated. This seems to restrict the grain size of sintered or hot pressed compacts to the original powder particle size, especially for fine powders. The presence of carbides through dissolution on etching is also indicated.

Discussion of Results and Conclusions

The fabrication of thorium powders by either hot pressing or cold pressing, sintering, and densifying by low temperature deformation appears to present no unusual problems. The main deterrent to consolidation using powder metallurgy techniques was oxidation. Resultant ThO$_2$ congregated in the grain boundaries. However, even with oxide contents approaching 5 pct ThO$_2$, the powders were easily fabricated to maximum density.

The coarse thorium powders did not sinter quite as readily as the fine particles because of the lower area of contacting surface. Nevertheless, they are the best for powder metallurgical applications. Although the calcium reduced powder was the most favorable of the fine powders as far as fabrication was concerned, the coarse powders represented by attritioned scrap and electrolytic flake were processed to density most easily, and the rate of oxidation, especially in the coarser fractions, was the lowest under fabrication conditions employed. In experimental operation, it was found easier to produce thorium powder by comminution of chips than to manufacture it by the hydride method. Inasmuch as this material seems to be every bit as good as the hydride powder, the procedure may be considered acceptable for recycling thorium machining scrap. In fact, machining scrap in chip form could be fabricated readily, especially by hot pressing without comminution. Therefore, powder metallurgy may be usefully employed in a variety of ways for the recycling of scrap thorium to solid metal.

Of all the techniques investigated in this work, the vacuum hot pressing process appears to be the most desirable consolidating method. With this technique, better and more uniform tensile properties were obtained, and the method was found to be generally more reliable than cold pressing and sintering. The lower temperatures involved in hot pressing allow a wide choice of furnace types. It is also possible to use metallic—mild or stainless steel and nickel—pressing dies of the type used commercially in the fabrication of large shapes of beryllium. When vacuum hot pressing beryllium, pressures as low as 100 to 200 psi may be used for consolidating the powder to density, providing the oxide content is not much above 1.5 pct BeO. In the case of thorium with oxide contents considerably in excess of this, pressures as high as 1200 psi had to be used, making the use of graphite dies mandatory. This, however, would also be true of beryllium with high oxide contents. Consequently, it may be possible that, as is the case with beryllium, if low oxide contents are maintained in vacuum pressing, high densification with low mechanical loads may be accomplished for thorium powder.

In all of the work on the fabrication of thorium by powder metallurgy, the evacuation was carried out to between 25 and 50 μ, which is now believed to be insufficient to prevent oxidation, especially with the finer powders. Lilliendahl has indicated that when sintering in argon at 1300°C about 250 ppm of oxygen was picked up, while in the present investigation sintering at 1400°C under 25 to 50 μ resulted in a pickup of 2000 ppm. In both cases calcium reduced powder was used. Consequently, further work in thorium powder metallurgy should utilize argon if the cold pressing and sintering op-

eration is desired. When using the coarser powders, even the vacuum achieved by a mechanical pump alone was generally sufficient. However, should finer powders be used and/or lower oxides desired, better vacuum conditions are recommended. If lower oxide contents would allow lower hot pressing pressures, and thorium could be processed using the methods developed for beryllium fabrication, thorium compacts up to a ton and a half in weight could be fabricated with available equipment.

Although it is suggested that hot pressing be considered for fabrication of coarse powders, a cold press-sinter work technique based especially on cold working above room temperatures—warm working—is recommended for finer powders. Temperatures of 400° to 500°C may be used without excessive oxidation whereby cold pressed and sintered bodies from 90 to 95 pct of maximum density are readily densified with low reduction ratios. If oxidation is restricted by suitable atmosphere control, mechanical properties approximating melted thorium may be achieved by powder metallurgical techniques.

Summary

Fabricating dense shapes from both primary and secondary thorium powders is quite feasible either by vacuum hot pressing or by cold pressing, vacuum sintering, and mechanical working. Even with oxide contents approaching 5 pct ThO_2, these powders are easily consolidated into bodies having maximum density and mechanical properties which compare well with wrought castings. Since the extensive steps of briqueting, melting, refining, casting, and *breakdown* working can be eliminated by applying powder metallurgy techniques directly to both powdered machining chips and to virgin reduced powders, the economic possibilities seem favorable.

Acknowledgments

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Technical Note

Hardness of Metals and Alloys

by G. P. Chatterjee

HARDNESS is one of the most common properties of metals and alloys but is one of the most difficult to define or express in terms of the fundamental units. In the Brinell or Vicker's hardness test, the hardness number N is defined as $N = L/A$ where L is the load in kilograms and A is the area in mm^2. This does not necessarily imply that a pressure of N kilograms per mm^2 actually acts on the specimen.[1] It is essential that for a true comparison of hardness values the angle of indentation be kept constant,[1, 2] which is not done in the Brinell test. For this and other reasons, the Brinell hardness value is not based on a satisfactory physical concept.[3] The concept of hardness based on the work done per unit volume of indentation[4-6] offers a simple and scientific definition. An attempt has been made here to develop this concept (at constant angle) and to compare the values so obtained with the Bhn for different metals and alloys.

In Fig. 1 a vertical load L is applied to a comparatively hard ball of diameter D creating an indentation of diameter δ and depth h on the specimen S. The work done, W, is then given by

$$W = \int_0^h L dh. \qquad [1]$$

Since L is not independent of h, Honda and Takahasi[4] and Matsumura[5] assumed different functions leading to equations which do not apply equally[6] to a wide variety of metals and alloys. A better relation is obtained from Meyer's Law

$$L = a\delta^n \qquad [2]$$

$$a = \frac{A}{D^{n-2}} \qquad [3]$$

where A and n are constants depending on the nature of the material but independent of the ball diameter D. From Fig. 1 it is obvious that

$$h = R(1 - \cos\theta)$$

and

$$\delta = 2R \sin\theta.$$

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Eq. 1 may then be written as

$$W = A2^2R^2 \tfrac{1}{2} \int_0^\theta \sin^{n+1}\theta \, d\theta. \qquad [4]$$

In Eq. 4 the indentation angle θ and the index n are both variables and n in general is not an integer. Suppose that

$$\frac{1}{2}\int_0^\theta \sin^{n+1}\theta \, d\theta = F(n) \qquad [5]$$

where $F(n)$ is some function of n for a given value of θ. If $F(\theta)$ and $G(\theta)$ are two independent functions of θ, then

$$\int_0^\theta F(\theta)\, G(\theta)\, d\theta \Big/ \int_0^\theta F(\theta)\, d\theta = f(\theta) \qquad [6]$$

where $f(\theta)$ is another function of θ defined by Eq. 6. Substituting $\sin^{n+1}\theta$ for $F(\theta)$ and $\log_e\sin\theta$ for $G(\theta)$, gives

$$\frac{1}{2}\int_0^\theta \sin^{n+1}\theta \log_e\sin\theta \, d\theta = f(\theta)\, \frac{1}{2}\int_0^\theta \sin^{n+1}\theta \, d\theta. \qquad [7]$$

From Eq. 5 it is obvious that

$$\frac{d\,F(n)}{dn} = \frac{1}{2}\int_0^\theta \sin^{n+1}\theta \log_e\sin\theta \, d\theta. \qquad [8]$$

Combining Eqs. 5, 7, and 8 gives

$$\frac{d\,F(n)}{dn} = f(\theta)\, F(n). \qquad [9]$$

Let

$$\beta = f(\theta) \qquad [10]$$

then

$$F(n) = \alpha e^{\beta n}. \qquad [11]$$

It may be noted from Eq. 10 that β is a function of θ but is independent of n. Hence, for a given value for θ, β may be taken as constant independent of the nature of the material. Combining Eqs. 4, 5, and 11 gives

$$W = A2^2 R^2 \alpha e^{\beta n}.$$

From Fig. 1, the volume V of the indentation is given by

$$V = \frac{\pi h^2}{3}(3R - h) = \frac{\pi R^3}{3}[2 - \cos\theta\,(\sin^2\theta + 2)].$$

The hardness H defined as W/V is therefore given by

$$H = \frac{W}{V} = \frac{A\,24\,\alpha\, e^{\beta n}}{\pi[2 - \cos\theta\,(\sin^2\theta + 2)]} = \frac{a(24\,D^{n-2}\,\alpha\, e^{\beta n})}{\pi[2 - \cos\theta\,(\sin^2\theta + 2)]}. \qquad [12]$$

For a given value of θ, values of $F(n)$ may be computed as a function of n from Eq. 5. Then, plotting $\log F(n)$ as a function of n, a straight line is obtained (see Eq. 11), the slope of which gives the value of β and the intercept the value of α. For $\theta = 30°$, $\alpha = 0.0525$ and $\beta = -0.9076$ are obtained. Substituting

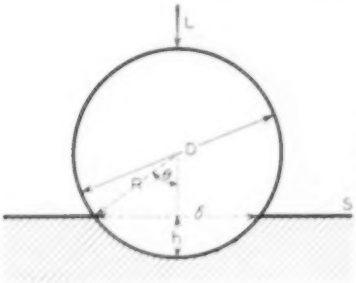

Fig. 1—Diagram shows vertical load *L* being applied to a comparatively hard ball of diameter *D*, creating an indentation of diameter δ and depth *h* on the specimen *S*.

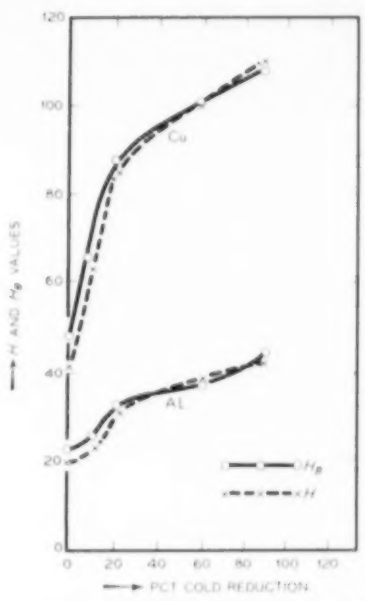

Fig. 2—*H* and H_B values are charted as functions of cold reduction for copper and aluminum.

the foregoing values of α, β, and θ in Eq. 12, for a ball diameter of 10 mm

$$H = a(10^{n-2}\,7.79\,e^{0.0525n})\ mm^{n-2} \qquad [13]$$

$$= a\,f_n\ mm^{n-2} \qquad [14]$$

are obtained, where

$$f_n = 10^{n-2}\,7.79\,e^{0.0525n}. \qquad [15]$$

For a given metal or alloy, the values of a and n may be easily obtained from Eqs. 2 and 3 by measuring two indentation diameters δ_1 and δ_2 corresponding to two known loads L_1 and L_2. Once the value of n is known, the value of f_n may be obtained from Eq. 15 or, more easily, from a plot of f_n as a function of n. The value of H is then easily obtained from Eq. 14 as a product of a and f_n. Values of a, n, and H were measured for different metals and alloys under different conditions of treatment. These are discussed in detail elsewhere. A typical plot is shown in Fig. 2. The corresponding Bhn's are indicated as H_B for comparison.

The limitation of this method is that Eq. 12 is based on Meyer's law which is empirical. Nevertheless, it is well known that, as long as the load is neither too small nor too large and it comes in equilibrium with the specimen, Meyer's law holds good[5] for wide varieties of metals and alloys under different conditions of treatment. The advantages, on the other hand, are that H defined as work done per unit volume of indentation offers a better physical concept and also a definite unit.[6] Moreover, the definition of H is based on a constant angle of indentation—a condition[1, 7] which offers more comparable hardness values than when the angle is made variables as in the Brinell test.

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Metallographic Identification of Nonmetallic Inclusions in Uranium

by R. F. Dickerson, A. F. Gerds, and D. A. Vaughan

ALTHOUGH the metallurgy of uranium has been under intensive study since the early 1940's, no systematic effort has been made to identify the nonmetallic inclusions in uranium. Uranium carbide (UC), which is probably the most common inclusion found in graphite-melted metal, has been tentatively identified by previous investigators, but the other nonmetallic inclusions have received little attention.

Since metallography is a valuable tool in metallurgical studies, the metallographic identification of the nonmetallic inclusions in uranium is important. Such an investigation has been completed and the identification of slag-type inclusions and of uranium monocarbide, uranium hydride, uranium dioxide, uranium monoxide, and uranium mononitride is described.

Metallographic Preparation

It is often possible to prepare specimens for metallographic examination equally well by several methods. The specimens which were examined in this work were prepared by one of two acceptable methods. For the convenience of the reader, both methods will be discussed in detail and will be referred to simply as Method I or Method II in the subsequent sections. For both Methods I and II, specimens for microscopic examination usually were mounted either in bakelite or in Paraplex room temperature mounting plastic.

Method I—Specimens were ground in a spray of water on a revolving disk covered successively with 120-, 240-, and 600-grit silicon carbide papers. It was necessary to perform the final grinding operation carefully on worn 600-grit paper to keep the scratches as fine as possible. After washing and drying, the specimens were polished for 3 to 4 min on a slow speed wheel (250 rpm) covered with a medium nap cloth. Diamet Hyprez *Blue* diamond polishing paste, Grade 00, 0 to 2 μ, was used as abrasive with kerosene as lubricant on the wheel.

Specimens were washed thoroughly in alcohol and final polished electrolytically in an electrolyte composed of 1 part stock solution (118 g CrO_3 dissolved in 100 cm^3 H_2O) with 4 parts of glacial acetic acid. A stainless steel cathode was used. At an open circuit potential of 40 v dc, a polishing time of 2 sec retained inclusions well with the bath at room temperature.

If additional etching was required to sharpen the interface between the metal and the inclusions, an electrolyte composed of 1 part stock solution (100 g CrO_3 and 100 cm^3 H_2O) and 18 parts glacial acetic acid was used at room temperature. Best results were obtained by etching for from 10 to 15 sec at 20 v dc in the open circuit.

Surfaces obtained by this method are suitable for microscopic examination. However, if desired, they may be etched further with other chemicals.

Method II—Rough grinding was done on a wet 180- or 240-grit continuous grinding belt. The specimen was then ground by hand successively on 240-, 400-, and 600-grit silicon carbide papers in a stream of water. Final polishing was accomplished on a 4 in. high speed wheel (3400 rpm) covered with Forstmann's cloth. Linde B levigated alumina, suspended in a 1 volume pct chromic acid solution, was the abrasive. Specimens usually were polished in 5 min or less by this technique.

Often the inclusions present in the metal were identified in the mechanically polished condition. When etching was required to outline inclusions more sharply, one of the two following methods was used. In the first method, the specimen is etched lightly while electropolishing in the chromic-acetic acid solution described above (1 part of stock solution to 4 parts of acetic acid). The electrolyte was refrigerated in a dry ice-ethyl alcohol bath and specimens were etched at 60 v dc on the open circuit for 2 or 3 cycles of 3 to 4 sec each. The second technique utilizes electrolytical etching at about 10 v dc (open circuit) in a 10 pct citric acid solution at room temperature.

X-Ray Diffraction Technique

The major problem in the identification of inclusions in metals by X-ray diffraction techniques is the extraction of a sufficient amount of each type of inclusion to obtain an X-ray diffraction pattern. In the present study, X-ray diffraction patterns were obtained from individual inclusions of the order of 10 μ diam. The polished and etched samples shown in the micrographs were examined at a magnification of X54 or X100 with a binocular microscope. This allowed sufficient working distance to extract the inclusions with a needle probe for powder X-ray diffraction analysis.

Friable inclusions such as MgF_2, CaF_2, UO_2, and UH_3 could be freed from the metal by probing the as-polished and etched surface. The fine particles then were picked up on the end of a Vistanex-coated glass rod (0.002 in. diam) which was held in a brass adapter made to fit the powder X-ray diffraction camera. The end of the glass rod was centered in the path of the X-ray beam.

In the case of the UC, UO, and UN inclusions which are smaller in size, more metallic in appearance, and less friable than the other inclusions, it was necessary to etch the inclusion in relief before extraction. UN inclusions etched sufficiently in relief in the electrolytic polishing solution described in Methods I and II by increasing the polishing time. UN inclusions were relief etched by extending the

R. F. DICKERSON, A. F. GERDS, and D. A. VAUGHAN are associated with Battelle Memorial Institute, Columbus, Ohio.

TP 4092E. Manuscript, Apr. 26, 1955. Philadelphia Meeting, October 1955.

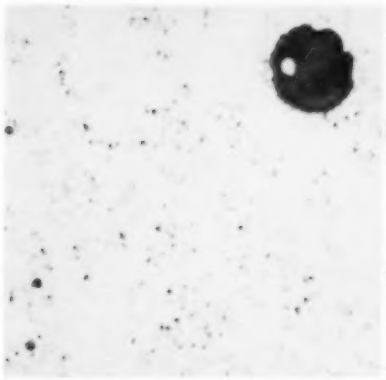

Fig. 1—Micrograph shows MgF_2 inclusion in upper right hand corner. Specimen was electroetched in chromic-acetic acid solution. X250. Area reduced approximately 25 pct for reproduction.

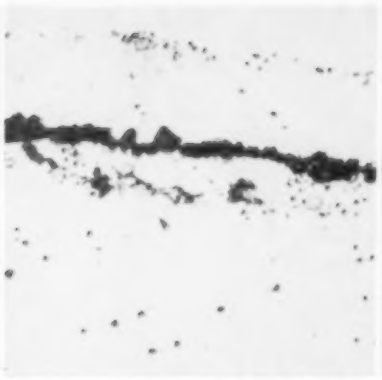

Fig. 2—Micrograph shows typical MgF_2 stringer as it appears in wrought uranium. Specimen was etched with 1:1 HNO_3-H_2O. X250. Area reduced approximately 25 pct for reproduction.

Fig. 3—Micrograph shows specimen containing carbon, as polished. The inclusions have been identified by X-ray techniques as UC. X250. Area reduced approximately 25 pct for reproduction.

time of the electrolytic etch described in Method II. The inclusion phase identified as UO was more difficult to etch for extraction as a single phase. A relief etch of this inclusion was obtained electrolytically in 1 part perchloric-10 parts acetic acid solution, run at 10 v dc. All etching was carried out in steps in order to follow the attack of the metal around specific inclusions, previously marked in the metallographic sample.

The identification of MgF_2, CaF_2, and UO_2 was made by comparison of the patterns from the inclusions with the diffraction data available in the ASTM card index. UH_3 was identified by comparison of its pattern with that reported by Rundle.[1] UH_3 has a cubic structure with $a_o = 6.63$A. UN, UO, and UC have face-centered-cubic structures with lattice constants of $a_o = 4.890$A, 4.920A, and 4.961A, respectively.[2] Identification was made on the basis of their measured lattice constants. Since UN, UO, and UC are reported to be mutually soluble in all proportions, the carbonitride U(C,N), containing approximately equimolar quantities of carbon and nitrogen, would have a lattice constant about equal to that of UO. Therefore, U(C,N) would not be distinguishable from UO by X-ray diffraction methods. Identification of UN and UC, however, is considered unequivocal on the basis of their measured lattice constants.

Identification of Inclusions

For the purposes of clarity, the metallographic identifications of the nonmetallic inclusions are discussed individually in the following sections. These sections are concerned specifically with the following inclusions: the fluorides (MgF_2 or CaF_2), uranium monocarbide (UC), uranium hydride (UH_3), uranium dioxide (UO_2), uranium monoxide (UO), and uranium mononitride (UN).

Fluoride Inclusions (MgF_2-CaF_2)—The fluoride inclusions, MgF_2 or CaF_2, may be observed as rather large glassy agglomerates in as-reduced or remelted metal. Of the two, the MgF_2 is probably the most abundant. When CaF_2 is observed, it is generally in conjunction with MgF_2. Positive identification of these inclusions was made by mechanically removing particles under the microscope from marked metallographic fields and subjecting the particles to X-ray diffraction analysis.

A typical example of the glassy MgF_2 inclusions found in as-reduced metal is illustrated in Fig. 1. This specific particle was identified by X-ray diffraction. The smaller light-colored inclusions which dominate the field are UN.

In wrought metal, the fluoride inclusions appear as stringers in the rolling direction and are generally surrounded by other nonmetallic inclusions. An example typical of these stringers is shown in Fig. 2.

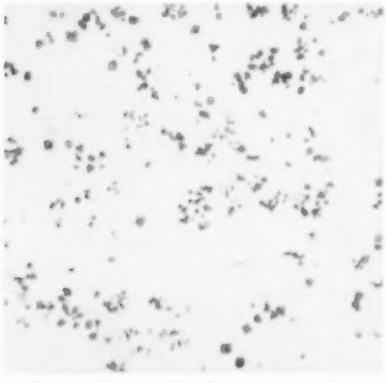

Fig. 4—Micrograph shows same field as in Fig. 3. Specimen was etched with 1:1 HNO_3-H_2O etchant. UC inclusions are darkened. X250. Area reduced approximately 25 pct for reproduction.

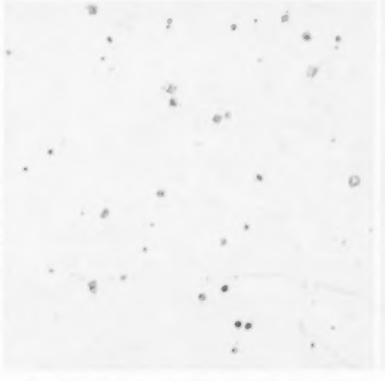

Fig. 5—Micrograph shows uranium containing 20 ppm C. Specimen was etched with 1:1 HNO_3-H_2O. UC is stained a dark color. X250. Area reduced approximately 25 pct for reproduction.

Fig. 6—Micrograph shows section of a graphite-melted ingot. The carbide particles show a cored structure. Specimen was lightly etched. X250. Area reduced approximately 25 pct for reproduction.

Fig. 7—Micrograph shows as-reduced uranium, arc-melted under partial pressure of helium. Specimen contains 0.7 ppm H, as polished. X250. Area reduced approximately 25 pct for reproduction.

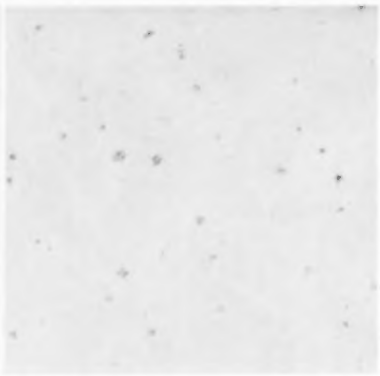

Fig. 8—Micrograph shows as-reduced uranium, arc-melted under hydrogen. Specimen contains 3.2 ppm H, as polished. Note lance-like hydride inclusions. X250. Area reduced approximately 25 pct for reproduction.

Fig. 9—Micrograph shows same section of field as Fig. 8. Detail of lance-like hydrides may be better observed. X500. Area reduced approximately 25 pct for reproduction.

The specimens illustrating the MgF_2 inclusions were prepared for examination by Method I, and each fluoride inclusion illustrated in Figs. 1 and 2 was removed and identified by X-ray diffraction techniques. The glassy appearance and the size and shape of these particles provide a means of identifying them without the aid of etchants. In many cases, identification may be made immediately after a 600-grit grind.

Uranium Monocarbide—Uranium monocarbide (UC) is probably the most abundant nonmetallic inclusion in graphite-melted uranium. Many investigators have tentatively identified the cubic gray inclusion which is found in graphite-melted metal as carbide. However, British investigators Mott and Haines[5, 6] studied uranium metal that was melted in air in graphite under a BaCl, slag, and reported the cubic gray inclusions which they observed to be UO_2.

In the present study of uranium carbide inclusions, initial effort was on the development of a suitable etchant. One was developed that darkened the carbides and did not visibly affect the other nonmetallic inclusions. This etchant, composed of 1 part nitric acid and 1 part water, is applied to the specimen by swabbing.

To check the validity of the nitric acid etchant, specimens containing known amounts of carbon were prepared for metallographic examination by Method I. A marked field was photographed in the polished condition, and the specimen was then etched and the marked field rephotographed. Following this, individual inclusions in the marked fields were mechanically extracted and identified as UC by X-ray diffraction. Figs. 3 and 4 show the field studied in a specimen.

It is interesting to note the clear white appearance of the unetched carbides in Fig. 3. This indicates that the gray color used for metallographic identification of the carbide is not always produced by polishing. Fig. 4 shows the identical field as Fig. 3, after using the nitric acid etchant.

These studies indicated that carbide inclusions cannot be identified by their shape alone, as was once believed possible. It is true that UC very often is observed as rectangular or cubic particles; but other inclusions, such as UN, may occur in similarly shaped particles. An example of this is shown in Fig. 5, a micrograph of as-reduced uranium etched with the nitric acid etchant. A study of Fig. 5 reveals that there are a few regularly shaped inclusions which have been darkened by the etchant. An interlacing network of very fine inclusions, which

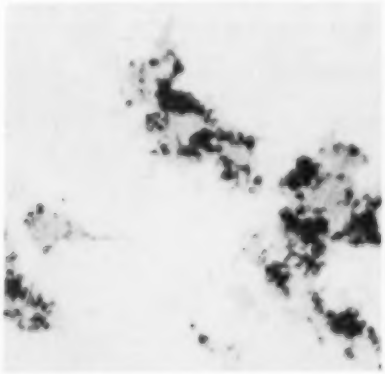

Fig. 10—Micrograph shows creamy-brown inclusion in an induction-melted uranium ingot, identified by X-ray analysis as UH_3. Specimen was etched with 10 pct citric acid. X500. Area reduced approximately 25 pct for reproduction.

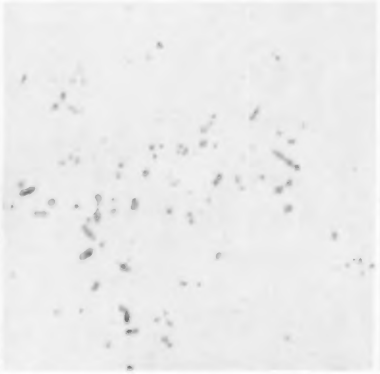

Fig. 11—Micrograph shows arc melt of as-reduced uranium to which UO_2 was added. The slate-gray inclusions have been identified as UO_2. Specimen contains 250 ppm O, as polished. X250. Area reduced approximately 25 pct for reproduction.

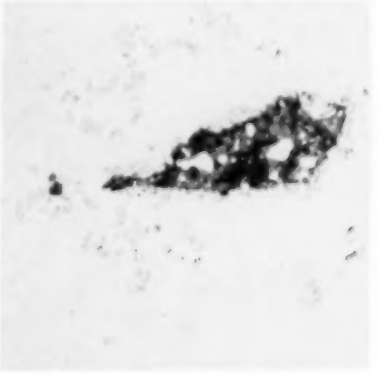

Fig. 12—Micrograph shows inclusion agglomerate in an ingot of uranium. The slate-gray material has been identified as UO_2. Specimen was etched with 1:1 HNO_3-H_2O. X250. Area reduced approximately 25 pct for reproduction.

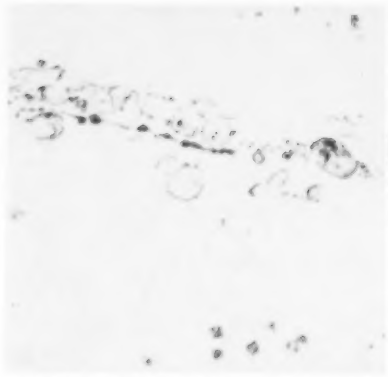

Fig. 13—Micrograph shows a stringer of UO inclusions as etched with 1:1 HNO_3-H_2O. The *fade-out* of some of the particles can be seen. X500. Area reduced approximately 25 pct for reproduction.

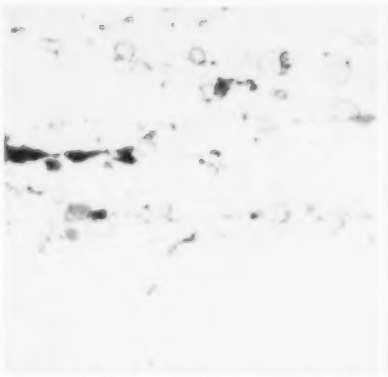

Fig. 14—Micrograph shows a small slag uranium oxide stringer in a rod. Dark matrix of stringer is MgF_2. Slate-gray particles are UO_2, and light-colored inclusions are UO. Specimen was etched with citric acid. X500. Area reduced approximately 25 pct for reproduction.

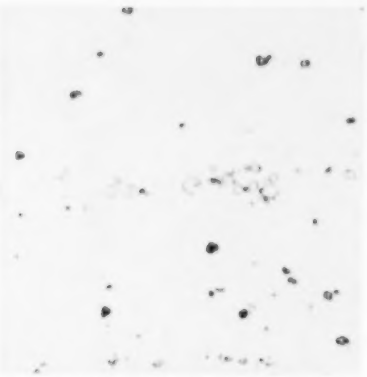

Fig. 15—Micrograph shows section of a rod etched with citric acid. The darkly stained particles are UC, and the rounded gray particles are UO. X250. Area reduced approximately 25 pct for reproduction.

are dark in color, is also shown. It appears that both the larger darkened inclusions and the fine network are UC. The regularly shaped inclusions which are white in color are probably UN. This specimen analyzed 20 ppm C, which is in agreement with the amount of carbide shown in the micrograph.

Fig. 6 shows a specimen prepared for examination by Method II. The cored-type structure often associated with the carbides is illustrated. This structure might suggest solubility of some element in the carbide phase.

An attempt was made to study the effect of nitrogen on the microstructure of the carbide by arc-melting some uranium carbide in a nitrogen atmosphere. Although the microstructure showed no evidence of coring, X-ray diffraction of the resultant specimen showed the presence of two phases: 1) face-centered-cubic UC with $a_o = 4.961$A, plus 2) an unidentified face-centered-cubic phase with $a_o = 4.950$A. Kjeldahl chemical analysis showed the nitrogen content of this specimen to be 1.6 wt pct.

Experiments of this type indicate the possibility of carbide-nitride intersolubility.[1] However, no further study on this approach was made.

Uranium Hydride—The hydride has probably the most distinctive appearance of all inclusions which may be present in uranium. In order to isolate the uranium hydride (UH_x), a series of arc melts was made to which varying amounts of hydrogen were added.

The base metal used for this work was as-reduced uranium. A sample of this metal was arc-melted in a copper crucible under a partial pressure of helium. This control sample was prepared for metallographic examination by Method I and is shown in Fig. 7. Vacuum-fusion analysis indicated a hydrogen content of 0.7 ppm.

A section of another uranium specimen, arc-melted under a partial pressure of hydrogen and containing 3.2 ppm H, is shown in Fig. 8. It will be noticed that there are many lance-like inclusions that appear light gray in the photograph. These are actually a creamy-brown color, which is distinctive among uranium inclusions. Fig. 9 shows a portion of the same field at a magnification of X500. The details of the hydride inclusions may be better observed in this micrograph.

Fig. 10 shows inclusions having the same color and general smooth appearance as those shown in Figs. 8 and 9. These inclusions were found in graphite-melted uranium. The inclusions shown in Fig. 10 were found in an ingot after casting. They were removed mechanically and identified by X-ray diffraction techniques as UH_x. Hydrides also have been observed in the form of stringers in the wrought metal.

The inclusions shown in Figs. 8 through 10 are typical of some of the forms in which the hydride appears in the metal. Correlation between hydrogen content as determined by vacuum-fusion analysis, and amount of the phase as seen under the microscope substantiated the X-ray identification of the hydride (UH_x) inclusions.

Uranium Dioxide—Uranium dioxide (UO_2) inclusions do not occur as frequently in graphite-melted metal as do UO or UC but, when present, they are relatively easy to identify metallographically. As is the case with most of the inclusions studied, the shapes of the UO_2 particles vary with the metal being examined. It is possible, however, to identify UO_2 by metallographic observation on the basis of its color. This can best be described as slate gray, a color frequently associated with oxides in other metals. The identification is aided by the fact that the color as observed under the microscope and as reproduced on a photographic print is very nearly the same.

Fig. 11 shows a specimen of as-reduced uranium which was arc-melted with an addition of UO_2. This material contained 260 ppm O. Dendritic, slate-gray inclusions, which were identified as UO_2 by X-ray diffraction studies, can be seen. The specimen was prepared for examination by Method II and was not etched.

Fig. 12 shows the occurrence of a large agglomerate of UO_2 in graphite-melted uranium and in metal to which UO_2 was added. The slate-gray material was removed by mechanical techniques and determined by X-ray diffraction to be UO_2. This specimen was prepared by Method I and etched with the nitric acid etchant.

Uranium Monoxide—The uranium monoxide (UO) inclusion is not noticeably affected by any of the electrolytic or chemical etchants that were studied. Because of this, and because of its mode of occurrence, it is one of the most difficult of the nonmetal-

Fig. 16—Micrograph shows uranium impregnated with nitrogen and arc-melted. Specimen contains 50 ppm N, as polished. X250. Area reduced approximately 25 pct for reproduction.

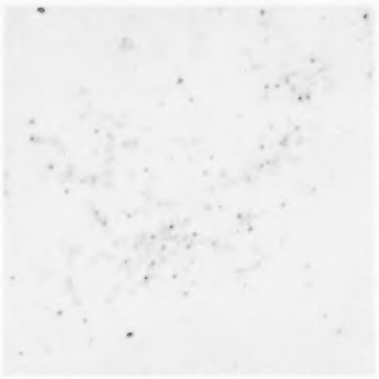

Fig. 17—Micrograph shows section of as-reduced uranium containing a concentration of UN identified by X-ray diffraction, as polished. X250. Area reduced approximately 25 pct for reproduction.

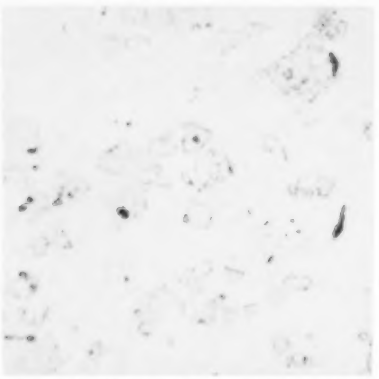

Fig. 18—Micrograph shows section of a uranium ingot induction-melted in a nitrogen atmosphere, as polished. Inclusions have been identified by X-ray diffraction as UN. X250. Area reduced approximately 25 pct for reproduction.

lics to identify by metallographic techniques. However, the UO particles have a characteristic that seems to be unique with them. In any given group of UO particles, there will be a few that seem to dissolve into the background metal. This can be noticed readily in specimens which have been etched with the nitric acid etchant, but a careful study of samples in the polished condition will also reveal the *fade-out*. Fig. 13 shows this fade-out as it occurs in particles of UO. The inclusions in this particular stringer have been identified as UO by X-ray diffraction techniques. Experience indicates that they do not occur as regular shapes with angular sides, but rather as rounded particles.

Fig. 14 is a micrograph of a portion of a small slag-oxide stringer. The specimen was prepared by Method II and was etched in the citric acid solution. The black matrix of the stringer is MgF_2, the slate-gray inclusions are UO_2, and the light-colored rounded particles are UO.

Fig. 15 shows a section of a rod polished by Method II and etched with the citric acid etchant. The micrograph shows UO inclusions as well as dark-stained carbides.

Uranium Mononitride—Uranium mononitride (UN) is the nitride in equilibrium with uranium at high temperatures. Unlike the higher oxide, UO_2, which is probably entrained in the metal with slag, the higher nitrides are not expected in graphite-melted uranium. Effort was concentrated, therefore, on attempts to identify UN inclusions.

The specimens used for this phase of the work were prepared from as-reduced metal. The metal was fabricated to ¼ in. rod and the rod sectioned in pieces about 1 in. long. A section of the rod was impregnated with 50 ppm N at 900°C and arc-melted. The resultant metal was sectioned and examined. The inclusions, shown in Fig. 16, were tentatively identified as UN. A variety of chemical and electrolytic etchants were used on these samples, but no definitive etchant for UN was found.

Fig. 17 shows a cluster of inclusions in a piece of as-reduced uranium that was identified by X-ray diffraction as UN. This specimen was prepared for examination by Method I. These irregular inclusions are very similar to those shown in Fig. 16.

A section of a uranium ingot that had been induction-melted under a nitrogen atmosphere appears in Fig. 18. The inclusions shown were identified by X-ray as UN. Unlike the inclusions found in Figs. 16 and 17, these are regularly shaped in the form of cubes that have been cut at various angles. Although the nitride particles appear similar to UO inclusions, they can be distinguished from UO by the fact that they do not exhibit fade-out.

When uranium metal containing UN as well as UO, UC, UO_2, and fluorides is etched with the 10 pct citric acid solution (Method II), a possible differentiation among the inclusions can be made. With this etchant, UC is stained golden brown while UO remains light gray. The appearance of UO_2 or the fluorides is unchanged. The UN inclusions assume a pinkish cast and, with a small amount of experience, can be readily distinguished from the other inclusions present. Unfortunately, these shadings cannot be shown in black-and-white photographs, where the color of the UN appears essentially the same as that of the UO.

As a result of the work described here with the UN inclusions, it is believed that metallographers may become familiar with the appearance of UN to such a degree that identification can be accomplished.

Conclusions

This investigation has developed metallographic means for distinguishing the several nonmetallic inclusions (MgF_2-CaF_2, UC, UH_3, UO, UO_2, and UN) in uranium. The work was done with the type of metal most commonly encountered by uranium metallographers. The methods described for identifying the various inclusions should prove useful in estimating metal quality.

Acknowledgments

The authors gratefully acknowledge the counsel and advice of M. W. Mallett, H. A. Saller, and C. M. Schwartz throughout the course of this work. They also acknowledge the metallographic assistance of D. M. Cheney. The work was performed under AEC Contract No. W-7405-eng-92.

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[3] B. W. Mott and H. R. Haines: *Journal* Inst. of Metals, London (1951-1952) **80**, p. 1390.
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Discussion of this paper sent (2 copies) to AIME by June 1, 1956 will appear in AIME *Transactions* Vol. **206**, 1956, and in JOURNAL OF METALS, October 1956.

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aime news

Pacific Northwest Sections Plan Conference

The Olympic Hotel in Seattle, Washington will be host to AIME members when they convene May 3 to 5 for the Fifth Pacific Northwest Regional Conference. Co-sponsored by the Oregon, North Pacific, and Columbia Sections, the conference will be addressed by Grover J. Holt, President-Elect of AIME. Mr. Holt, who is general manager of the ore mining dept., Cleveland-Cliffs Iron Co., Ishpeming, Mich., will be the featured speaker at the banquet scheduled for Friday evening, May 4. Earl R. Marble, American Smelting & Refining Co., Tacoma, will serve as toastmaster.

The impressive roster of speakers includes J. Gordon Parr, assoc. prof. of metallurgy, University of Alberta, who will address the Metals Branch Luncheon on Thursday, answering the query, *How Does the Metallurgist Get the Urge?* The Mining Branch will hear Desmond F. Kidd, CIM Past-President and president and general manager of Attwood Copper Mines Ltd., who will speak on *This Progress of Ours*, at the luncheon scheduled for May 4.

Mr. Kidd, who has been a consulting geologist since 1935, graduated from the University of British Columbia where he received a B.S. degree in Geological Engineering. He went on to earn a Ph.D. at Princeton in 1933. While an undergraduate, he became student assistant with the Geological Survey of Canada and by 1930 held the position of staff geologist. From 1929 to 1931, Kidd was a member of the group that completed the geological exploration of the northwest coast of Hudson Bay. Later, he investigated the uranium deposits in Great Bear Lake. A member of AIME since 1942, Mr. Kidd was president of CIM for the year 1952–3.

A choice of three tours is open to those attending. In Seattle, a visit to the Kaiser Gypsum Co. wallboard plant has been arranged. It is one of the most modern in the industry and the only one of its kind in the Pacific Northwest. This trip will also include stops at the Glacier Sand & Gravel Co., a Kaiser subsidiary, and the portland cement distribution plant, Permanente Cement Co.

Visitors to Renton will be shown through the extensive plant of the Pacific Car & Foundry Co., while the Tacoma bound group will take in the American Smelting & Refining Co. copper smelter and refinery and the Kaiser aluminum reduction plant. Round-trip bus transportation has been arranged for all the tours. Ladies are invited to all conference activities including the plant trips.

THURSDAY, MAY 3

9:30 am — **Room B**

Physical Metallurgy Division

Chairman: E. C. Roberts, Associate Professor of Metallurgical Engineering, University of Washington, Seattle

Resistance of Aluminum to Pitting Corrosion in Sea Water: T. J. Summerson, research chemist, and M. J. Pryor, assistant director, dept. of metallurgical research, Kaiser Aluminum & Chemical Corp., Spokane.

Hot Water Corrosion of Zirconium: M. D. Carver and E. T. Hayes, physical metallurgy branch, U. S. Bureau of Mines, Albany, Ore.

Hydrogen Pickup of Titanium and Zirconium During Processing and Fabrication: H. Kato and R. L. Carpenter, U. S. Bureau of Mines, Albany, Ore.

Metallography of Irradiated Materials: J. R. Morgan, radiometallurgy unit, Hanford Atomic Product Operation, General Electric Co., Richland, Wash.

Properties of the Heat-Treatable Alloys, 7178, 7079, and 6066: M. C. Fetzer, head, physical metallurgy branch, dept. of metallurgical research, Kaiser Aluminum & Chemical Corp., Spokane.

12:30 pm — **Olympic Bowl**

Metals Branch Luncheon

Toastmaster: J. G. Johnston, chief metallurgist, Bethlehem Pacific Coast Steel Corp., Seattle.

Speaker: J. Gordon Parr, associate professor of metallurgy, University of Alberta, Edmonton.

Subject: "How Does the Metallurgist Get the Urge?"

2:00 pm — **Room B**

Physical Metallurgy Division

Chairman: Earl C. Roberts, School of Mineral Engineering, University of Washington, Seattle

Studies of Iron-Chromium Alloys: H. G. Anderson, school of mineral engineering, University of Washington, Seattle.

Some Effects of Particle Size on Phase Transformations: J. G. Parr, associate professor of metallurgy, dept. of mining and metallurgy, University of Alberta, Edmonton.

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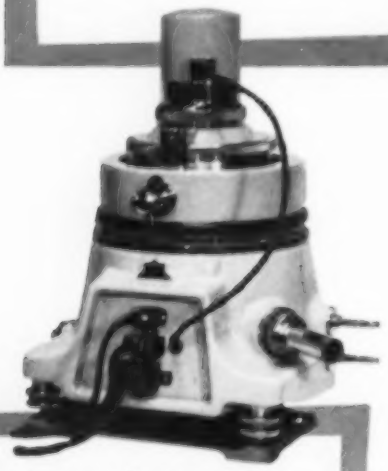

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Dispersion Hardening of Lead and Zinc—An Interim Report: D. N. Williams, assistant chief, and R. I. Jaffee, chief, nonferrous physical metallurgy div., Battelle Memorial Institute, Columbus, Ohio.

Magnetic Properties of Quaternary Alloys Based on the Composition, $Mn_nAl_nC_nX$: F. S. Death and L. Howe, graduate students, and H. P. Myers, assistant professor of metal physics, University of British Columbia, Vancouver.

FRIDAY, MAY 4

9:00 am — Room B

Iron and Steel Division

Chairman: Lloyd Banning, Chief, Branch of Pyrometallurgy, U. S. Bureau of Mines, Albany, Ore.

A Metallurgical Evaluation of Scrap for West Coast Ingot Production: L. W. Heinzinger, metallurgical supervisor, Bethlehem Pacific Coast Steel Corp., Seattle.

Steelmaking Processes in the United States—Trends and Some Recent Developments: J. C. O. Harris, iron and steel specialist, U. S. Bureau of Mines, Washington, D. C.

A New Approach in Electric Pig Iron Smelting: F. C. Collin, research manager, Als, Oslo, Norway, and O. A. Grytting, chief, smelting section, Electro Kemisk's Research Station, at Fiskaa Verk, Kristiansand, Norway.

A New Merchant Bar Mill in Alberta: G. R. Heffernan, managing director, Premier Steel Mills Ltd., Edmonton, Alberta.

Procurement of Quality Steel for Aircraft Use: Fred Herr, Boeing Airplane Co., Seattle.

2:00 pm — Junior Ballroom

Extractive Metallurgy Division

Chairman: R. E. Shinkoskey, Manager, Tacoma Smelter, American Smelting & Refining Co., Tacoma, Wash.

High Analysis Phosphates for the West: R. J. McNally, assistant manager, sulfuric acid and liquid SO_2 dept., American Smelting & Refining Co., Salt Lake City.

Ore and Concentrate Handling and Bedding at the Tacoma Smelter: Martin L. Plass, assistant general superintendent, American Smelting & Refining Co., Tacoma, Wash.

Cominco's New Sinter Plant: E. A. Mitchell, superintendent, smelting dept., J. F. Melvin, plant superintendent, sintering plant, and R. Bainbridge, assistant superintendent of development, Consolidated Mining & Smelting Co. Ltd., Trail, B. C., Canada.

Nodulizing Practice at Manganese, Inc.: W. Kendrick, kiln superintendent, Manganese Inc., Henderson, Nev.

6:00 pm — Junior Ballroom

Pre-Banquet Cocktail Hour

Admission by Banquet ticket.

7:00 pm — Olympic Bowl

Conference Banquet

Toastmaster: Earl R. Marble, American Smelting & Refining Co., Tacoma, Wash.

Speaker: Grover J. Holt, AIME President-Elect, and general manager, ore mining dept., Cleveland-Cliffs Iron Co., Ishpeming, Mich.

New York Sets All-Time Attendance Record

Topping all previous records, the AIME Annual Meeting held in New York February 20 to 23, saw a turnout of 4178. To accommodate this large attendance, AIME split their meetings between two hotels, the New Yorker for the Metals Branch and the Statler for Mining and Petroleum Branches. When the groups joined forces for the Annual Banquet on February 22, they needed the largest hotel for this sellout affair, which prompted the choice of the Waldorf-Astoria.

For those so minded, the Annual Meeting schedule packed the spaces between the sessions with an array of breakfasts, luncheons and dinners. The New York Section deserves particular credit for the entertainment at the Monday night Dinner-Smoker, and for the caliber of the music and prizes at the Informal Dance which followed the Branch Dinners Tuesday night.

Welcoming Meeting

The first major event was the Welcoming Luncheon Monday noon at which time President H. DeWitt Smith introduced C. E. Reistle, president-elect of AIME. Alfred N. Penhale, representing the CIM, brought greetings from Canada.

The luncheon featured a speech by Jesse C. Johnson, director of the div. of raw materials, AEC. Discussing *The Romance of Uranium*, he pointed out that, "Uranium prospecting has attracted more people, including people without mining experience, than any other mining excitement since the 1849 gold rush . . ."

Mr. Johnson closed his speech with the following remarks:

"This is only the first chapter in the romance of uranium mining. Under the stimulus of military requirements, the uranium industry is approaching a $500 million a year business. The real market will come with a development of atomic power."

The decision to change the AIME to include Petroleum Engineers, first suggested at last year's Annual Meeting, was made official at a special business meeting of the national convention on Tuesday afternoon.

Metals Branch Dinner

That evening the Metals Branch Dinner was the scene of the presentation of a number of major awards. Chairman J. H. Scaff conferred the Robert W. Hunt Award, in absentia, on Otwin Cuscoleca of Austria for his work in developing the oxygen process for steelmaking. This process has been used in the operation of steelworks in the U. S., Canada, Europe, S. A., and the Far East.

Others who were honored include M. O. Holowaty who received the J. E. Johnson, Jr. Award for his studies in improving the permeability and productivity of the sintering process; J. J. Gilman whose work in the field of plasticity of crystals, won him the Rossiter W. Raymond Award. The Mathewson Gold Medals were given to Earl R. Parker, Jack Washburn and Eugene H. Edwards. Guest speaker at this dinner was Erwin R. Biel, professor of meteorology at Rutgers who described *The Influence of Weather on You*.

Meetings—Sessions—Lectures

The business meetings began with the Council of Section Delegates who met on Saturday morning. Sunday was devoted to the educators who convened all day at Columbia University. Then on Monday four full days of technical sessions commenced.

Annual Meeting

Unusual circumstances surrounded two men scheduled to be honored by the AIME. Due to the untimely death of Father James B. Macelwane, shortly before the annual meeting, the Jackling Lecture was cancelled. Fred J. Mick made the presentation of the award plaque which was accepted by Ross Heinrich on behalf of St. Louis University where Father Macelwane had served as Dean and professor of geophysical engineering.

The Howe Memorial Lecture was presented posthumously in behalf of Herbert J. French of International Nickel Co. Inc., whose death in August, 1955 ended a brilliant career in metallurgy. John W. Sands of Inco's research div. delivered the speech which he had completed in collaboration with Oscar O. Miller, head of the company's research laboratory, steel section. They were able to draw upon material accumulated by Mr. French, on the commercial history of engineering alloy steels.

Tracing this history back to 1869, the lecture recalled that the earliest steels were heavily over-alloyed for protection, which proved unsound economically. Then as technological

At the Welcoming Luncheon on Monday the guests caught something of the romance of uranium in the talk by guest Jessie Johnson, head of raw materials activity for the AEC. Left to right: L. E. Elkins, A. B. Kinzel, Jessie Johnson, and AIME Presidents H. DeWitt Smith, and C. E. Reistle, Jr.

advances were made, it was found that the less expensive steels could be used satisfactorily.

The Institute of Metals Annual Lecture on Wednesday morning featured a speech by Andre Guinier of Paris who discussed *The Precipitation Phenomena in Supersaturated Alloys*. This division lecture was under the supervision of chairmen H. DeWitt Smith and J. S. Smart.

Formalities at the Extractive Metallurgy Div. Stag Luncheon were ably expedited by A. W. Schlechten who also presented a plaque to past div. chairman P. T. Stroup. Also presented for the first time was the EMD award to T. R. A. Davey, an Australian now in Germany. Guest lecturer at the luncheon was Dean Curtis L. Wilson of the Missouri School of Mines who spoke on *The Road to Survival*.

Presiding over the Bessemer Centennial Luncheon on Thursday, Feb. 23 was A. B. Wilder, Chairman of the Bessemer Steel Committee. Commemorating 100 years of steelmaking, the group also talked of a proposed trip to the Lorain Works of U. S. Steel scheduled for April 25, 1956. Howard Biers, Union Carbide & Carbon Corp., also introduced the foreign visitors present.

Annual Banquet

Highlighting the many varied activities was the Annual Banquet, streamlined this year to include only the major awards. Chairman and Toastmaster H. DeWitt Smith honored the following men: Charles R. Kuzell who received the James Douglas Medal; Louis Buchman recipient of the William Lawrence Saunders Medal and R. Livingston Ireland, the Erskine Ramsay Medalist. The Robert H. Richards Award went to Arthur W. Fahrenwald; and the Benjamin F. Fairless Award to Stephen M. Jenks. The speech to the Banquet audience by Carl E. Reistle, Jr., incoming AIME president, appeared in the March issues of JOURNAL OF METALS and MINING ENGINEERING in "Drift". A special feature at the Banquet was a talk by Secretary of the Treasury George M. Humphrey, who was voted an Honorary Member of AIME.

The citation given Mr. Humphrey was presented "in recognition of his able administration of large corporate enterprises in the U. S., his imaginative and far-sighted leadership in opening up the vast iron deposits of Labrador, his achievements and service to the nation as Secretary of the Treasury, and the sound judgment, integrity, understanding and courage which are his and which have brought him great responsibility and high honor at home and abroad."

Louis S. Cates, of Phelps Dodge Corp. who also became an Honorary Member, was cited for "his outstanding development and administration of the low grade copper enterprises in Utah, at the Utah Copper Co., and, in Arizona, at the Ray Consolidated Copper Corp. and the Phelps Dodge Corp. His eminence as a leader in these fields deeply warrants this recognition by the Institute he has served so well as President, and, for many years, Director."

AIME's new president, C. E. Reistle, Jr., presented the Charles F. Rand Medal to H. DeWitt Smith "for distinguished achievement and inspired leadership in the administration of all phases of the Mining Industry."

Among the many activities of the WAAIME was a luncheon fashion show at the Waldorf-Astoria on February 22, *Thirty Years of Fashions*, presented by Mary Gordon, travel adviser to TWA.

Credit Where Credit is Due

Members responsible for the success of the Annual Meeting include: General Committee: John H. Ffoliott, Chairman; James S. Vanick; Alvin W. Knoerr and Sidney S. Goodwin, Vice-chairmen; G. Howard Le Fevre, Secretary; Walter P. Schmid, Treasurer.

Reception Committee: Robert Fulton, Chairman; Forrest E. Allen, Evan Just, Milton A. Lagergren, J. R. C. Mann, Richard D. Mollison and Frank N. Spencer.

Banquet Committee: C. DeWitt Smith, Chairman; John T. Sherman, Vice Chairman; Austin Goodyear, Charles A. R. Lambly, Frederick R. McIntosh, Mrs. Domingo Moreno, Mrs. David E. Park, Earl M. Rees and Richard P. Seelig.

Dinner-Smoker Committee: David T. Steele, Chairman; A. L. Hotch, William Mudge, J. K. Reynolds, Robert Stanley.

Welcoming Luncheon Committee: Julian W. Feiss, Chairman; J. R. Atkinson, Philip Bucky, Norman H. Donald, Jr., Richard W. English, Mrs. Evan Just, Mrs. J. R. C. Mann and Lendall P. Warriner.

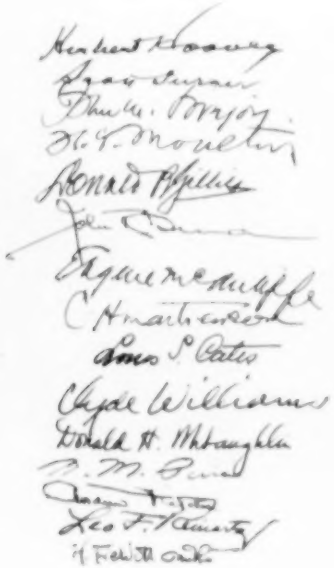
Informal Dance Committee: Louis Pierre Ledoux, Chairman; Charles Gow, Carleton S. Harloff, Mrs. Robert Hills and Russ McIntyre.

Cocktail Party Committee: James Boyd, Chairman; Phillip L. Merritt, Robert H. Ramsey, Earl M. Rees and John F. Ryan.

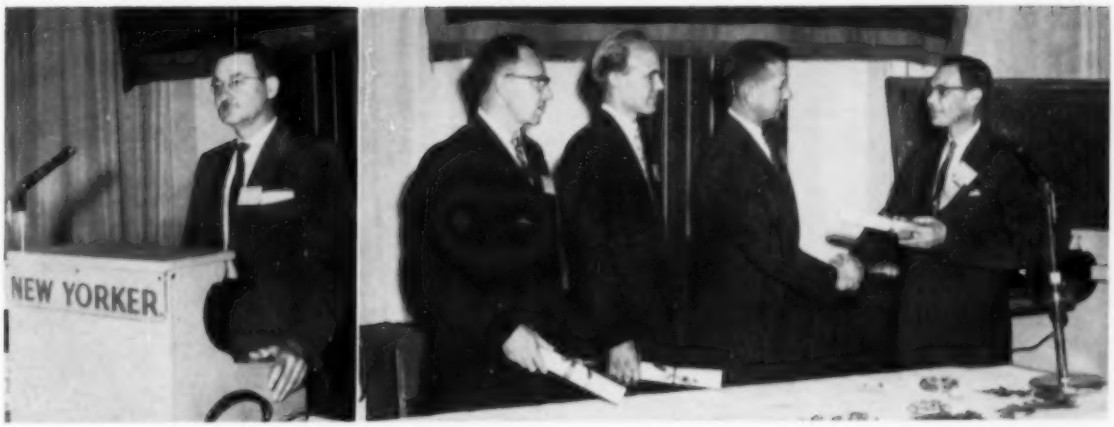
Souvenirs Committee: L. H. Hart and Edward M. Connaughton.

Ladies Entertainment Committee included: Mrs. H. DeWitt Smith and Mrs. C. E. Reistle, Jr., Honorary Chairmen; Mrs. H. R. Norsworthy, Chairman; Mrs. D. E. Park, Vice Chairman.

Past Presidents Gather



A private luncheon of AIME Past Presidents brought together: (seated, left to right) Donald B. Gilles, Scott Turner, Herbert Hoover, John M. Lovejoy, and Herbert G. Moulton; (standing, left to right) H. DeWitt Smith, W. M. Peirce, John R. Suman, Eugene McAuliffe, Champion H. Mathewson, Louis S. Cates, Donald McLaughlin, Clyde Williams, Andrew Fletcher, and Leo F. Reinartz. At right is the signature sheet passed around the group during the meeting.



RIGHT: At the Metals Branch Dinner, outgoing Institute of Metals Div. Chairman J. S. Smart makes the presentation of the Mathewson Gold Medal to the co-winners, Earl R. Parker, Jack Washburn, and Eugene H. Edwards. LEFT: Jack Scaff, outgoing chairman of the Metals Branch Council was the toastmaster at the Metals Dinner—scene of award presentations as well as of interesting talk on how the weather can be changed.

Session Reports

Iron and Steel Division

Oxygen Steelmaking—The widespread interest in the use of oxygen to increase production rates in steelmaking was shown by the large attendance at this session. Approximately 250 were present to hear the two papers presented.

G. W. Healy and D. C. Hilty of Electro-Metallurgical Co. described their methods for calculating the heat balance of an electric furnace during oxygen blowing and for estimating the concurrent change in chromium analysis in the manufacture of high chromium steels. Of particular importance and interest were the data on blowing rates which indicated that the smaller the heat size, the larger the critical oxygen input rate required to maintain the action. If the oxygen input rate does not exceed this critical rate, the bath loses temperature and fails to decarburize satisfactorily. Also of considerable interest were the data showing that the curve of temperature versus oxygen input flattens at high blowing rates, and that the maximum temperature attained is more a function of the initial chromium content than the amount of oxygen used. The discussion afterward emphasized the importance of silicon content and the desirability of low silicon in the charge.

Lively discussion followed A. J. Kesterton's paper describing the use of an oxygen lance through the open hearth roof at the Steel Co. of Wales, Ltd. Dr. Kesterton detailed the mechanism developed for a permanent roof installation to introduce oxygen through a water-cooled lance in the center of the open hearth furnace, and the results of making several thousand 225-ton heats. As much as 1½ hours heat time has been saved in the manufacture of .07 carbon rimming steels. In practice, the use of oxygen is started as soon as the bath is melted level, or when the carbon content is below .45%. At this point, the oxygen lance is lowered to about 4" above the bath, a bath sample is taken for chemical analysis, and the oxygen blow started. When the carbon analysis of the bath is available, the quantity of oxygen required for decarburization is calculated. An integrator on the oxygen recorder continually records the amount of oxygen used. As soon as the required volume of oxygen has been delivered, the furnace is tapped without further reference to the carbon analysis.

Discussion of Dr. Kesterton's presentation showed the considerable interest in this new development in open hearth steelmaking. The advantages in increased productivity are highly attractive. It is safe to predict that additional installations for oxygen injection through the open hearth roof will soon be made. —*G. H. Enzian.*

Hydrogen in Steel—An audience of 250 attended the joint session of the ISD and IMD to hear discussions on the most recent investigations on the effects of hydrogen in steel and the behavior of hydrogen in steelmaking and steelmaking slags. C. R. Simcoe of Battelle Memorial Institute reviewed the effects of hydrogen in steel and the situations which recently have focused attention on hydrogen as a possible contributing cause of catastrophic failures in service. B. B. Muvdi reported on the effects of hydrogen in embrittling specimens of ultra high strength 4340 steels which had been cathodically cleaned or plated. Failure under sustained load was found to result from development of a surface crack which, through growth, reduced the load-bearing cross section.

W. J. Barnett discussed recent studies on crack propagation induced by hydrogen and its relation to brittle fracture of steel. He was followed by Henry Epstein who dealt with the behavior of hydrogen in steelmaking in acid open hearth, basic open hearth, and basic electric arc furnaces. In each type of furnace the hydrogen content was observed

Leaders of the Womens Auxiliary present at New York included Mrs. H. DeWitt Smith, Mrs. Theodore Nagle, Mrs. H. W. Hardinge, WAAIME President Mrs. Robert D. Coombs, Mrs. C. W. Clarke, Mrs. H. A. Prasser, and Mrs. Reed W. Hyde. Mrs. Clarke, Mrs. Prasser, and Mrs. Hyde are from Canada.

At the Powder Metallurgy Luncheon, left to right: G. L. Bibbins, P. Kalischer, H. Hausner, Carl Johnson, C. G. Goetzel, S. J. Grant, F. V. Lenel, and Oliver Preston.

Featured speaker at the Extractive Metallurgy Div. Luncheon was Dean Curtis L. Wilson, whose topic emphasized the dangers facing our civilization if we are too complacent.

to decrease during the carbon boil and to sharply increase at such time as the bath action was stopped. J. H. Walsh supplemented the latter results by showing the relative levels of hydrogen in the slags for the same heats studied by Mr. Epstein. The availability of a reliable technique for determining the hydrogen content of slags promises to provide significant advancement in understanding and controlling the behavior of hydrogen in steelmaking.—*D. L. McBride.*

Hydrogen Embrittlement—The session, held jointly with ISD on Wednesday morning, was under the direction of chairmen Harold Margolin and D. J. McPherson. The opening speaker, E. J. Ripling, Continental Can Co., pointed out the analogy between steel and hydrogen embrittlement of a commercial alpha-beta titanium alloy. The same type of strain rate effects are observed in both materials. The next two reports presented by Robert I. Jaffee were prepared in collaboration with his co-workers at the Battelle Memorial Institute, G. A. Lenning and C. M. Craighead (now deceased). In the discussions following the first paper, *The Effect of Testing Variables on the Hydrogen Embrittlement of Titanium and a Ti-8Mn Alloy*, some significant Westinghouse research results were revealed. These showed that porosity was obtained in zirconium-hydrogen alloys after tensile testing. The holes corresponded to the previous location of the zirconium hydride and thus accounted for the lower ductility.—*H. Margolin.*

Symposium on Structure of Slags, Mattes, and Fused Salts—At the joint session with the Iron and Steel Div. the lead-off paper was a review of our present knowledge of slag structure prepared by Professor R. Schuhmann, Jr., of Purdue University. Interpreting the properties of slags in terms of structural models will suggest experiments and can lead to the design of slags with desirable properties, even though we have incomplete knowledge of the ultimate structure.

L. Yang then presented data showing that the addition of 20 mol pct CuCl to Cu_2S lowered the conductivity to less than one fourth the value of pure Cu_2S and increased the current efficiency from 0 to 70 pct. This shows that the conductivity of Cu_2S is largely electronic but transforms to ionic when CuCl is added.

John Chipman then presented data on the diffusion constants of calcium and silicon determined by the radioactive tracer method. These values, together with data on conductivity and viscosity, permit calculation of the probable ion forms. Earl Roland described a back emf method for simple determination of equilibrium and decomposition potentials of metal deposition reactions in fused salt systems.—*G. Derge and R. C. Buehl.*

Sintering—This session began with a paper on *Reducibility of Iron Ores* by G. Odone and G. Milanese of the Cornigliano Co. of Italy, presented by E. Marshall. The authors, who conducted their tests in hydrogen and carbon monoxide atmosphere, reported results similar to those obtained by other investigators.

T. L. Joseph presented a very interesting paper on *Reaction Zones in the Iron Ore Sintering Process* prepared in collaboration with R. D. Burlingame and G. Bitsianes. By quenching the sintering bed at various stages of the process and subsequently impregnating the bed with plastic mounting material, the authors were able to show the individual zones in which drying, calcining, reduction and fusion reactions were taking place.

The paper entitled *Effect of Sinter Mix Composition and Additions on the Quality of Blast Furnace Sinter* by E. C. Rudolphy, C. W. Boquist and D. J. Carney, U. S. Steel Corp., was presented by Mr. Rudolphy. Among the additions found to improve the quality of sinter were roll scale, ore fines, return fines, blast furnace slag, and carbon. Lime and magnesia had a detrimental effect on the quality of sinter.

At the conclusion of the reports, the group was given the rare opportunity to view an unscheduled film on the European Low Shaft Blast Furnace which was presented and explained by P. Coheur of Liege, Belgium. A lively discussion on sintering and low shaft blast furnace problems ended this morning session.—*M. O. Holowaty.*

At the Bessemer Centennial Luncheon, left to right: (standing) W. McGerrity, S. J. Dougherty, L. T. Sanchez, K. L. Fetters, K. E. Snyder, J. F. O'Brien, J. P. Ely, W. H. Mayo, A. J. Sottile, and C. C. Benton; (seated) G. McMorran, A. B. Wilder, H. Graham, G. Yocom, J. M. Stone, R. E. Edwards, and F. J. McMulkin.

Picture Roundup at the Annual Meeting

Among the guests at the Annual Banquet were Assistant Secretary of the Interior Felix Wormser, Mrs. Wormser, Honorary Member and Secretary of the Treasury George Humphrey, and AIME Past President Donald Gilles.

Award winners in the Metals Branch included the members of this group at the Annual Banquet. Left to right: Earl R. Parker, Otwin Cuscoleca, Eugene H. Edwards, John J. Gilman, and Jack Washburn.

Two of the Student Prize Paper winners compare notes. Left, E. A. Freeburg, and right, Mrs. and Mr. W. L. Steinbrenner. Mr. Steinbrenner's paper was entered by the Pittsburgh Section.

Mrs. M. O. Holowaty looks well pleased as she stands with her husband, winner of the J. E. Johnson, Jr. award.

Institute of Metals Division Session Reports

Teaching of Metallurgy to Nonmetallurgists—This session of the Education Committee was held on Sunday at the Columbia University Faculty Club. Devoted primarily to teaching in engineering schools and universities, the program featured talks by John Wulff, Massachusetts Institute of Technology, A. J. Shaler, Pennsylvania State University and G. T. Horne, Carnegie Institute of Technology. They described the service courses offered by their departments, emphasizing the objectives of these classes.

John P. Nielsen, New York University, summarized the results of a questionnaire which had been answered by 40 departments of metallurgy. A spirited discussion followed, which covered teaching technique, motivation of students and instructors and subject matter, especially the extreme range extending from materials engineering to a simplified physics-of-solids approach.

In the second half of the session, the employer's point of view was expressed. J. F. Young of General Electric Co., stressed the need for training in fundamentals in this period of rapidly changing technology. H. H. Hanink, Curtis Wright Corp., analyzed the functions of the materials engineer in an industry producing mechanical equipment, and underscored the importance of practical knowledge. These talks were followed by lively discussion which also encompassed the position of the metallurgist in nonmetallurgical companies.

Research Summaries on Powder Metallurgy—The first two papers of the morning session were presented together by E. M. Wise on behalf of the English authors, C. E. Richards, E. V. Walker, and A. C. Lynch, and H. Evans, C. G. Smith, and D. K. Worn. Their prime concern was with the production of permalloy sheet using the powder metallurgy technique.

The next two papers dealt with titanium carbide cermets. H. Blumenthal and R. Silverman drew attention to the influence of various factors on infiltration. L. P. Skolnick described the microstructural changes observed after various infiltration times and offered a possible explanation.

The remaining three papers were concerned with SAP. In a paper presented by S. K. Nowak, the French authors, J. Herenguel, P. LeLong, and M. LeNouaille, showed that SAP can be anodised although the conditions of treatment differ from those

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used for conventional aluminum. F. Lenel and his collaborators approached the difficult problem of the metallography of aluminum powder extrusions by employing carbon film replicas under the electron microscope.

During a luncheon of the Powder Metallurgy Committee at large, the outgoing chairman, C. G. Goetzel, gave a brief review of the activities of the committee during the past year and of the considerable expansion which the field as a whole has experienced in 1955. New officers were installed for the year 1956-57. The new chairman, C. Johnson, briefly advanced plans for the forthcoming activities of the committee.

The speaker at the afternoon symposium session was N. J. Grant of M.I.T., who talked *on SAP and Related Processes.* After discussing the properties and nature of SAP on the basis of work previously carried out in the laboratory, Professor Grant went on to describe more recent work on materials made from mixing very fine metal and metal oxide powders.

Professor Grant was assisted by his colleague, O. Preston, in answering numerous questions. The importance of the metal—metal oxide bond—and the merits of adding dispersions by internal oxidation were topics raised in the discussion.—*Claus G. Goetzel.*

Titanium Symposium—Under the able leadership of Julian Glasser and W. R. Opie, about 225 persons were brought up to date on production of titanium sponge and ingots. P. J. Maddex underlined the growth of the industry. In 1955, 1900 tons of finished titanium was produced, worth $60 million—the value for 1956 will be double this. While value is going up, price is going down—in two years sponge has gone from $5.00 to $3.45 per lb.

C. G. Hatch described electric furnace smelting of Allard Lake ore to produce a 70 pct TiO_2-7 pct Fe slag and a good 2 pct C iron product.

R. J. Krieger used an excellent group of slides to illustrate the work which has insured sound low-hydrogen nonsegregated ingots of a size comparable to 5 or 6 tons of steel. Double vacuum melting of consumable electrodes and use of master alloys are the principal advances.

M. A. Steinberg thoroughly covered information available on various extraction processes: while sodium reduction of $TiCl_4$ is commercial, oxide processes are not. The most promising electrolytic process appears to be based on consumable anodes.

During the very active discussion, audience and panel alike contributed. Sponge produced in 1955 was 4100 tons. Kroll process $MgCl_2$ is very pure and easily recycled. A. C. melting of ingots is not used but should be investigated. Kellogg's paper was referred to for general "not unrealistic" cost figures. I. E. Weber of GSA gave $3-5000 per ton-year as capitalization cost. Since about 99.5 pct of present producers are confident of new processes, present prices reflect high R&E costs. Mr. Alexander of ICI confirmed their $3.00 sponge price. While new processes may not be continuous, a distinct improvement over the Kroll process should be possible. MgO-base chrome magnesite refractories are used in the smelting furnaces.—*O. W. Moles.*

Powder Metallurgy—The annual seminar session Thursday afternoon was addressed by N. J. Grant on *SAP Type Materials.* Dr. Grant described the experiments he and his colleagues have made at Massachusetts Institute of Technology, on copper base and nickel base materials, which contain an insoluble oxide as a second phase. These materials, as well as molybdenum base materials studied at Battelle Memorial Institute, are characterized by improved stress-rupture properties at elevated temperatures. These properties are attributed to the same strengthening mechanism which operates in extrusions made of flake aluminum powder (SAP) such as the strengthening effect of an insoluble second phase very finely divided in a metallic matrix. Although the work on these materials, on bases other than aluminum, is still in its beginning, it has aroused great interest because of potential applications for high temperature materials.

Dr. Grant's presentation was followed by a very lively discussion which lasted over an hour and underscored how little is known yet in this new field.—*F. V. Lenel.*

Diffusion and Internal Friction—At the Tuesday morning session the mechanism of self-diffusion occupied the attention of an audience of approximately 100 listeners, as three of the speakers covered various aspects of the subject. P. G. Shewmon discussed the variation of the self-diffusion coefficient with orientation in magesium single crystals. R. A. Swalin showed that the diffusion coefficients of solutes in dilute nickel base substitutional solid solutions were not much greater than the self-diffusion coefficient of unalloyed nickel. This interesting result was somewhat unexpected. C. E. Birchenall demonstrated the marked increase in the self-diffusion coefficient of iron in austenite resulting from carbon enrichment.

The next part of the meeting was enlivened by a stimulating critique by A. S. Nowick, of the application of internal friction techniques to determine the nature of grain boundaries in metals. Dr. Nowick reviewed the recent results on grain boundary viscosity obtained by authors S. Pearson and L. Rotherham of the UK Atomic Energy Authority, who were unable to attend in person. E. E. Stansbury contributed additional information obtained from in-

ternal friction studies on silver and silver-base solutions.

The meeting concluded with a presentation by M. Herman of the effects of the order-disorder transformation on creep in the beta-brass system.—*Louis S. Castleman.*

Nuclear Metallurgy—The second of a series of symposia arranged by the IMD nuclear metallurgy committee was held on Monday afternoon, February 20, under the chairmanship of B. Lustman, Westinghouse Electric Corp. and H. A. Saller, Battelle Memorial Institute. Of chief concern were problems encountered in the application of more common structural materials in the various reactor environments which have been investigated. The interest of AIME membership was evidenced by the peak attendance of 250.

The introductory speaker, R. C. Dalzell, acting head of the AEC, Engineering Div., discussed the types of problems common to the application of materials in reactor environments. D. H. Gurinsky, Brookhaven National Laboratory, then analyzed the behavior of materials in molten aggressive metal environments especially molten lead and bismuth. E. G. Brush, General Electric Co., detailed the equally interesting and severe problems raised by the use of less aggressive liquid metal coolants such as sodium and sodium-potassium alloys which are employed in the reactor built to propel the submarine *Sea Wolf*. S. Greenberg, Argonne National Laboratory, discussed the different classes of phenomena which occur when the structural materials of reactors are exposed to low temperature water or to organic liquids.

Again, as pointed out by D. M. Wroughton, Westinghouse Electric Corp., an entirely new set of parameters and conditions are imposed by the use of high temperature pressurized water as a coolant. Much of the experience on material behavior gathered in the course of development and operation of the submarine, *Nautilus*, and its prototype at Arco, Idaho, was described. The final paper, by G. P. Smith of Oak Ridge National Laboratory, dealt with corrosion of materials in fused hydroxide environments. Those problems common to all reactor environments, as well as those unique to this particular coolant, were emphasized.

All six of these articles were available, prior to presentation at the meeting, in the second volume of the IMD Special Report Series devoted to nuclear metallurgy. Copies of this volume are still available from the AIME.—*B. Lustman.*

Deformation and Recrystallization—This lively and crowded session was concerned with the development of textures and deformation behavior. N. Ujiiye and R. Maddin discussed the textures produced by cold rolling molybdenum single crystals. G. W. Wiener and Robert Corcoran reported on deformation and recrys-

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tallization textures in polycrystalline silicon iron, which included as a variable, the influence of sulfide particles.

P. A. Beck presented a paper by Alfonso Merlini of France, concerning the annealing textures in cold rolled copper sheet. Here again, retention of deformation texture components was observed on annealing at low temperature.

W. R. Hibbard, Jr. reported studies of preferred orientations and magnetic properties of the permanent magnet alloys cunife, cunico, silmanal and vicalloy. Attempts were made to correlate the textures and magnetic properties on the basis of magnetic and crystallographic phenomena.

F. L. Vogel, Jr. discussed etch pits revealing dislocations in plastically bent germanium crystals before and after annealing. On annealing, the number of dislocations was reduced to the minimum number required by the crystal curvature, the density became more uniform from surface to neutral axis, and the dislocations were rearranged into low angle boundaries. C. E. Sims and R. I. Jaffee reported measurements of the elastic modulus of rhenium as a function of temperature, its stress rupture behavior, its tensile strength and elongation as rolled and as annealed, its thermoelectric properties and its resistance to attack by molten metals. J. H. Keeler found a linear relationship between flow stress of zirconium iron alloys and volume fraction of particles, despite a considerable variation in particle size and shape. This observation and the temperature dependence of particle strengthening were debated in relation to current theories. H. A. Lequear and J. D. Lubahn reported that a sudden change of stress in a creep test of an aluminum alloy did not produce the unusual transient that was observed when the strain rate was rapidly altered in a tensile test. J. R. Low, Jr. reported that brittle fracture of a titanium carbide-inconel cermet could be effected when the larger carbide particles were cracked first, followed by cracking of adjacent smaller particles and finally by rupture of the inconel matrix.—*R. L. Fullman.*

Semiconductors—This second annual IMD symposium took place on Feb. 21 under the chairmanship of Baldwin Sawyer and S. J. Angello. The morning session consisted of three review papers in the field of semiconductors, convering the topics of technology, physics, and dislocations in semiconductors. In the afternoon session, the short research papers provoked lively discussion.

The next AIME symposium on semiconductors is scheduled for the February 1957 session to be held in New Orleans. Those interested in participating are urged to communicate with W. G. Pfann, Bell Telephone Laboratories, Murray Hill, N. J.—*W. G. Pfann.*

Extractive Metallurgy

Physical Chemistry of Roasting—In the introductory paper, H. H. Kellogg discussed the various reactions which may take place during the roasting of sulfides and outlined the stoichiometric and thermodynamic considerations which govern them.

M. W. Wadsworth then described the application of kinetic measurements to the determination of roasting mechanisms. Using the roasting of sphalerite and molybdenite as examples, he illustrated how various rate laws may be encountered and how these may be interpreted.

The two subsequent papers illustrated an alternative approach to the elucidation of roasting mechanisms, based on physical examination of the products. Using micrographic and X-ray diffraction techniques, P. G. Thornhill and L. M. Pidgeon showed that during the roasting of particles of sphalerite and pyrite, no change occurred in the sulfide kernels. With other sulfides the metal or sulfur component showed preferential oxidation. C. L. McCabe and J. Morgan described related studies in which the nature of the primary products formed on roasting various sulfides, and the permeabilities of the oxidized layers, were determined.

In the final paper, R. B. Thompson and B. H. McLeod discussed various aspects of the fluidized roasting of pyrite, ranging from the operating principles and description of FluoSolid reactors to the results of a detailed microscopic examination of the calcines produced in such systems.—*J. Halpern.*

Refractories—The large attendance at the session held on Monday morning attested to the importance of this aspect of extractive metallurgy. One hundred and fifty members heard the papers by A. E. Fitzgerald and Guy Bridgstock in which increased service life and lower operating costs, through use of suspended basic refractories in copper anode furnaces, were indicated.

The report by J. E. Dore and W. S. Peterson, based on the primary aluminum industry, showed the divergence of the problems in aluminum melting from those usual in higher temperature refractory fields. Of paramount importance is the control of metal penetration, secured by limitation of silicate phase in alumina-silica refractories, or by firing of plastic fire-clay compositions below the transformation temperature of meta-kaolin. However, the low fired plastic compositions had insufficient abrasion resistance. In contrast, W. H. Stewart's paper showed good abrasion resistance for low moisture 85 pct alumina ramming mixes in secondary metal monolithic hearth construction.

Lack of time curtailed what promised to be a lively discussion of the above two papers, and of the *Survey of Refractories for Lead Operations* by A. Paul Thompson.—*J. C. Hicks.*

Lead, Zinc, and Cadmium—This session opened with a paper by R. Bainbridge entitled *Cooling and Conditioning Fume Laden Gases at Cominco.* Portions of this work had been published previously, and it was of interest to learn of the further fundamental investigations on this subject being carried out at Cominco.

Horizontal Retort Charging Machines was presented by J. W. Burgess. Design details of the various machines currently in use at the zinc smelters in the natural gas belt were outlined in some detail.

T. D. Jones gave V. F. Leferrer's paper on *Vacuum Dezincing of Parkes' Process Zinc Crusts.* His able and interesting presentation indicated his familiarity with the subject. Of particular interest is the fact that this distillation is carried out at low vacuum and low temperature so that only the zinc is distilled.

The closing paper, by R. E. Lund, was *An Early Commercial Application of Sulphate Roasting.* Mr. Lund described revisions made over the past few years, of the treatment process for sinter gas fume collected in electrostatic precipitators at the Josephtown smelter.—*J. A. Marvin.*

Lead Smelting—Five papers were presented to the 68 members attending on Tuesday afternoon. *The St. Joe New Lead Sintering Plant* was discussed by J. W. Sherman who emphasized their present 100,000 ton capacity.

R. R. McNaughton, Associate Chairman of the session, read the paper by H. E. Lee and D. Ingvoldstad on the *Modernization of Bunker Hill Pre-Sintering Plant.* After two years' operation, this plant has demonstrated a marked increase in blast furnace smelting rate due to their unique approach and improvements in sintering.

The *Sinter Roasting of Lead-Rich Galena Concentrates at the Electrothermic Lead Plant of the Ronnskar Works, Sweden,* was described by I. M. Symonds. The paper, prepared by S. J. Wallden, N. B. Lindvall and K. G. Gorling, explains the Boliden method for electrothermic-roast-reaction-smelting.

T. D. Jones presented a paper on *Debismuthizing Lead with Magnesium and Potassium at Noyelles-Godault* written by J. Iche. Emphasized are the importance of pre-refining of lead to free it of antimony and arsenic, since these elements form compounds with magnesium and potassium before bismuth does.

Debismuthizing of Lead by T. R. A. Davey was read to the group by A. W. Schlecten. The paper describes how chemical lead (<0.005 pct Bi) may be produced by the Jollivet or Dittmer processes. Also discussed are the principles by which bismuth may be removed by the presentation of quantitative diagrams, with brief mention of practical aspects.—*H. L. Johnson.*

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Physical Chemistry—About 60 members and non-members attended this session on Thursday afternoon.

In the opening paper presented by H. L. Bishop on *Slag-Metal Equilibrium Under Lime-Silica-Iron Oxide Slags*, Mr. Bishop, co-authors N. J. Grant and J. Chipman, showed good agreement between predicted equilibrium constants and those measured with the usual assumptions about species and some unknown activity coefficients. The second paper on the *Rate and Mechanism of Sulfur Transfer between Carbon-Saturated Iron and Slags* was offered by S. Ramachandran who prepared it in collaboration with T. B. King and N. J. Grant. This very interesting work was done in order to show that stoichiometric equivalents Fe, Si, S, and CO were interrelated in the sulfur transfer experiments performed.

The third paper by J. P. Morris and G. R. Zellars was entitled the *Vapor Pressure of Liquid Copper and Activities in Iron-Copper Alloys*. Morris showed that the carrier gas method, in which the gas was in intimate contact with the liquid metal or alloy, was an extremely useful method for determining activities.

The last paper by J. W. Burlingame and N. A. Gokcen was on the *MnO-SiO$_2$ System*. The authors redetermined portions of the phase diagram. Several attending thought that the manganous-manganic ratio needed to be determined, while others thought that a congruently melting compound might exist.—*Richard E. Grace.*

New Methods in Hydrometallurgy—The session was held as scheduled on Feb. 23, E. B. Mancke, chairman, and H. G. Poole, recorder, changing roles for the last half of the session. Considerable interest was evidenced by the good attendance. The opening topic was manganese recovery from domestic ores, and a brief discussion followed the papers by E. S. Nossen and Charles Prasky.

As the meeting progressed, the amount of discussion increased. The next two papers dealt with ion exchange, the first by R. S. Long and R. S. Olson was concerned with design considerations. John Dasher, A. M. Gaudin and R. D. Macdonald explored the use of ion exchange in extractive metallurgy.

The final paper on new flocculents, by Mr. Olson, provoked animated discussion from the audience. Of particular interest also were Prof. Gaudin's comments concerning his current studies. These show that the size and shape of containers in which settling tests of slurries are made, have a great influence on the estimated size of thickeners required. The implication is that settling tests made in the conventional manner may give misleading results. Prof. Gaudin offered to send information on this subject to those requesting it from him at the Massachusetts Institute of Technology.—*E. B. Mancke.*

Zinc Smelting—This symposium on fluid-bed roasting of zinc concentrates was led by J. G. Wehn and F. M. Stephens, Associate Chairmen. No formal papers were presented, but a brief history of four companies' operations was given by the panel members representing them.

Mr. Brubaker, Aluminum Co. of Canada, described the fluid bed operation at Arvida, Quebec, which consists of a 22 ft diam reactor. At first the unit encountered trouble with scaling, densification and with the ball-check valves in the orifice plate. These valves were then removed and the bed depth lowered from 6 ft down to 3 ft in order to cut excess retention time which had caused densification. With the modified unit, 200 tons of zinc concentrates can be treated daily.

B. F. Buff outlined the operation of the two 18 ft diam reactors at the National Zinc Co. plant in Bartlesville, Okla. He pointed out that the units operate with a 20 to 30 pct excess supply of air. Eight water spray units mounted in a circular pattern in the roof maintain temperature control.

The New Jersey Zinc Co., N. Y., formerly used flash roasting to treat their zinc concentrates, W. M. Pierce revealed. However, after studying alternate methods of roasting they now use a three-stage roasting process in the single reactor without separation plates, merely by adding the air in increments up the side of the reactor. The reactor is 2 ft by 10 ft with a flared top to lower the final space velocity. With this unit, zinc concentrates can be roasted at rates of 2.4 to 3.5 tons per sq ft of furnace area per day. Mr. Pierce noted that the cost of operating this system is on a par with that of flash roasting.

Robert Redlefs traced the operations at St. Joseph Lead Co., Josephtown, Pa., back to 1948 when they began studying fluid-bed reactors with a one-inch plexiglass model, operated cold. By 1953 a 15 ft reactor was being used and in 1955, the first 22 ft commercial unit was placed in operation, the novel feature being a hot cyclone system. The cooling agent used is excess sulfate liquor, 33 gal per ton of partially deleaded concentrates.—*F. M. Stephens, Jr.*

Extractive Metallurgy of Uranium—The first paper presented at this session was a summary by W. L. Lennemann of the processes used in various uranium mills on the Colorado Plateau.

R. L. Philippone described the conversion of a uranium mill at Monticello, Utah from a salt roast-carbonate leach circuit in which both the uranium and vanadium were solubilized and subsequently recovered, to a circuit in which the salt roast step was omitted and only the uranium was recovered.

The extensive pilot plant testing of a recent development in the field of uranium metallurgy was described by C. K. McArthur. The development of this process has made it possible to recover uranium directly from desanded pulps by contacting the slimes with an ion exchange resin, eliminating the need for filtration of the pulps.

A. M. Gaudin described the history of the development of the acid leaching-ion exchange process used in the South African plants for the recovery of uranium from the ores and tailings from gold mining operations.—*J. S. Breitenstein.*

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Neil O. Johnson will be in charge of Foote Mineral Company's spodumene mine and ore processing plant at King's Mountain, N. C. The new plant manager leaves the dept. of explosives at E. I. du Pont de Nemours of Wilmington, Del. where he has served since 1939 as technical representative. Johnson has had extensive mining experience; he was associated with the Hog Mountain Gold Mining & Milling Co. of Birmingham. He also served as engineer with The Dorr Co., N. Y. A World War II Engineer Corps Major, Mr. Johnson served in Alaska on the famous Alcan highway project. Later he became project officer, Army-Navy Board, as consultant on design equipment. He is a graduate of the Colorado School of Mines and a member of Tau Beta Pi, honorary scholastic fraternity.

FRED W. DEMONEY

Fred W. DeMoney has been appointed head of the mechanical metallurgy and evaluation section of Kaiser Aluminum & Chemical Corp.'s metallurgical research dept. at Spokane. **Roger Olleman** was chosen as assistant section head. Prior to joining Kaiser Aluminum, Dr. DeMoney served as research metallurgist with Dow Chemical Co. and staff engineer with Kimberly Clark Corp. He graduated from Illinois Institute of Technology and received his Ph.D. degree from the University of Minnesota where he also served as a research fellow and instructor. Dr. DeMoney is a member of ASM and AIME. Dr. Olleman, was formerly associated with Westinghouse Electric Corp. He studied at the University of Washington and Carnegie Institute of Technology, receiving his Ph.D. from the University of Pittsburgh. ASTM awarded him their Templin prize for his work in connection with metal testing techniques at low temperatures. He is a member of ASM, AIME and ASME.

Max Huber has resigned from his post with Battelle Memorial Institute to join the staff of Union Carbide Europe in Geneva, Switzerland, as metallurgical engineer in their special steel division.

E. G. HOLMBERG

R. B. Fuller, International Minerals & Chemical Corp., was named special consultant to the phosphate minerals div., where he has been assistant to the vice president since 1953. Previously, Mr. Fuller was manager of the company's Florida phosphate dept. In 1951 he received an honorary Doctor of Law degree from Florida Southern College. He will continue to reside in Mulberry, Fla.

John Symonds is now engaged in research for E. I. du Pont de Nemours & Co. Mr. Symonds previously was associated with the Pyrites Co. in Wilmington, Delaware.

Francis B. Speaker has been appointed consultant on mining matters in the Office of Minerals Mobilization. Mr. Speaker is an engineer at Hewitt-Robins Inc., Stamford, Conn. He was chief of the nonferrous metals div. of the War Production Board and director of the Mining Division of the Defense Materials Agency during the Korean War.

Howard E. Stoneback, formerly vice president of Central Boiler & Mfg. Co. is now president and treasurer of Fabsteel Sales & Engineering Co., Detroit.

Ralph L. Hennebach has been promoted to assistant general manager, western department of the American Smelting & Refining Co. with offices in Salt Lake City.

Charles R. Heath is now associated with the Northwestern Metal Co., located in Lincoln, Neb.

Ferrucio Fabriani is professor of metallurgy, National School of Engineering, University of Brazil, Rio de Janeiro.

E. G. Holmberg has joined the corrosion engineering section of the International Nickel Co.'s development and research div., New York. Before coming to Inco, he was chief metallurgist, Alloy Steel Products, Linden, N. J. Prior to that, Mr. Holmberg had served for 11 years as a metallurgist with E. I. du Pont de Nemours & Co. at its Belle Works in West Virginia. He also taught engineering at the Newark School of Fine Industrial Arts, in New Jersey for three years. A graduate of the Colorado School of Mines, Mr. Holmberg has written many articles on corrosion. He is a member of ASM, ASTM, the Electrochemical Society, National Association of Corrosion Engineers and the American Petroleum Institute.

Arthur P. Guidi has joined Texas Foundries, Inc. in Lufkin, Texas, as assistant to the plant manager. He was formerly with the Texas Electric Steel Casting Co. in Houston.

T. V. Philip has joined the dept. of mining and metallurgy of the University of Illinois as a research associate. He recently completed his doctorate in metallurgical engineering at the University of Wisconsin, Madison, Wis.

Martin J. Hughes, former superintendent of ore mines for the Lone Star Steel Co., Texas, is now mining engineer at Kaiser Steel Corp., Eagle Mountain, Calif.

WILLIAM R. TOEPLITZ

William R. Toeplitz is the new president of Bound Brook Oil-Less Bearing Co., N. J., filling the vacancy left by the death of **William Fisher Jennings** who passed away last September. Mr. Toeplitz, who joined the company in 1935 as a metallurgical engineer, has been vice president in charge of engineering, since 1944. Considered one of the country's foremost authorities on powder metallurgy, he is a graduate of Lehigh University, and a member of AIME, ASTM, and SAE.

FRANK E. GARRATT

GILBERT SOLER

Frank E. Garratt, formerly general superintendent of Universal-Cyclops Steel Corp., has been appointed works manager at the Bridgeville, Pa. plant, and **Gilbert Soler** promoted to technical director. Mr. Garratt, who has been associated with the company for 21 years, is a graduate of the Carnegie Institute of Technology where he specialized in management engineering. Gilbert Soler joined Universal Cyclops in 1953 as assistant technical director. He has been an AIME director and a member of the Electric Furnace and Open Hearth executive committees.

John M. Schreiner has been named division manager of the National Carbon Co., Union Carbide & Carbon Co. in New York.

Michael V. Nevitt, formerly associate professor at Virginia Polytechnic Institute, Blacksburg, Va., has accepted a post as associate physical metallurgist with the AEC Argonne National Laboratory in Lemont, Ill.

Gunther Mohling has been named chief metallurgist, Allegheny Ludlum Steel Corp. He replaces **Rush Lincoln** who has been promoted to technical director of the organization. Other changes announced are: **W. W. Drykacz,** new manager of quality control, Watervliet Plant, to replace Dr. Mohling; **E. E. Reynolds** will be the new associate director of research to fill the vacancy left by Mr. Drykacz.

Born in Westphalia, Germany, Dr. Mohling attended schools there and in 1927 received his Ph.D. from the University of Munich. He worked in the German steel industry, later as a geologist in Mexico. In 1930, he joined the International Nickel Co. in New Jersey. Dr. Mohling has served for six years on the High Temperature Metals Committee of the National Advisory Committee for Aeronautics and received the President's medal for his work on high temperature alloys used in jet aircraft.

Mr. Dyrkacz is a native of Arnold, Pa. In 1942 he received his degree from Carnegie Institute of Technology and did graduate work at Rensselaer Polytechnic Institute. He has been associated with General Electric Corp., Cameron Manufacturing Co., Emporium, Pa., and joined Allegheny Ludlum in 1949. He is on several panels of the materials advisory board of the National Academy of Science. Dr. Reynolds was born in Utica, Ohio and received his Ph.D. from the University of Michigan in 1950. He was a laboratory assistant at the Spicer Manufacturing Co. and joined the Watervliet plant in 1950 as supervisor of valve steel research. In 1952 he was chosen to head the high temperature alloy section.

James K. Stanley will supervise the silicon steels and magnetic materials research section of Crucible Steel Co. of America with offices in Pittsburgh. Prior to his appointment with Crucible, Dr. Stanley was supervisor of metallurgy in the materials div. of Standard Oil Co. His wide experience includes research for National Smelting Co. and Westinghouse Electric Corp. The author of a book, *Metallurgy and Magnetism,* Dr. Stanley is a member of AIME and ASM. He was born in Cleveland, studied at Western Reserve University and Carnegie Institute of Technology. He received his Doctorate from the University of Pittsburgh.

Norman Hackerman, chemistry professor, University of Texas, and **Mars G. Fontana,** prof. of metallurgical engineering at Ohio State University received the 1956 awards of the National Assn. of Corrosion Engineers at the NACE Twelfth Annual Conference banquet on March 14 in the Hotel Statler, New York. NACE elected the following officers for 1956-57: president—**W. F. Fair,** tar products div., Koppers Co. Inc., Pittsburgh; vice president—**W. H. Stewart,** Sun Pipe Line Co., Beaumont, Tex. Re-elected as treasurer was **R. A. Brannon,** Humble Pipe Line Co. Also elected were three directors: **H. L. Bilhartz,** Production Profits Inc., Dallas; **Hugh L. Hamilton** of A. V. Smith Engineering Co., Narberth, Pa.; **A. L. Stegner,** Tennessee Gas Transmission Co., Houston.

Apr. 15, 1956, is the deadline for papers that are to be presented at the Institute of Metals Div. Fall Meeting in Cleveland, Oct. 8 to 10, 1956. Papers received by this deadline but requiring revision may not be processed in time to permit scheduling for this meeting.

Obituaries

Charles W. Merrill

An Appreciation by
Herbert S. Shuey

Charles W. Merrill (Legion of Honor Member 1892), internationally known San Francisco metallurgical engineer, died Feb. 6, in Honolulu.

Mr. Merrill, holder of the James Douglas Medal of the AIME and a former regent of the University of California, his alma mater, was in the midst of one of his frequent visits to Hawaii, and had been ill only three days. He was 86.

Born in Concord, New Hampshire, Dec. 21, 1869, Mr. Merrill was brought to San Francisco as an infant by his parents; and, although his work in the metallurgical field took him over the globe, he had maintained residence in the San Francisco Bay area all his life.

Receiving his elementary education in the public schools of San Francisco and Alameda, Mr. Merrill graduated from the University of California with the class of 1891, and immediately entered upon the career which was to bring him international fame for his development, design, installation, and operation of numerous gold extraction plants in the U. S., Canada, and Mexico. These plants were based on his own patents involving various processes for the recovery of gold from complex ores. At various times Mr. Merrill held more than 25 patents on metallurgical processes and their application, many of which proved so successful as to be ultimately adopted by most of the large gold and silver mines throughout the world.

Upon graduation from college, Mr. Merrill spent a short time as assistant to Dr. George B. Becker, Chief of the U. S. Geological Survey. Later that year (1891) he met and went to work for the eminent metallurgist, Alexis Janin, whose brother—the mining engineer Louis Janin—introduced him to another mining engineer—Herbert Hoover. Mr. Merrill spent three years with Alexis Janin

in San Francisco, working in the laboratory on metallurgical problems.

Having prepared his graduation thesis on the cyanide process for recovering gold from its ores, Mr. Merrill was anxious to install a plant for commercial application; and, after leaving the employ of Alexis Jamin, struck out for himself. He went to Bodie, Calif., and, after studying the tailings of the Standard Consolidated Mine there, proposed to its superintendent, Mr. Thomas H. Leggett, the erection of an experimental plant. Mr. Leggett agreed; the plant was built and proved completely successful.

After his work at Bodie, Calif., Mr. Merrill then spent about two years at the rich Harqua Hala Mine in Arizona. There he persuaded its superintendent, Robert M. Raymond, to let him install a cyanide plant, which likewise proved successful.

Shortly after completing this project, Mr. Merrill met two mining engineer friends—Messrs. Wartenweiler and Bratnober—who told him of the operations of the Montana Mining Co. at Marysville, Mont. Mr. Merrill went there and induced its manager, A. T. Bayliss, to install an experimental plant. When this plant had demonstrated that the mine's tailings could be profitably reworked, a large operating plant was installed, of which Mr. Merrill had charge as resident engineer, continuing in the capacity of consultant for several years.

In 1898 Mr. Merrill, after extended study of the operations of the famed Homestake Mine at Lead, S. D., entered into a contract with Homestake Mining Co. to install a cyanide plant for recovery of gold from tailings, and spent ten years in directing this highly successful operation—an operation which resulted in recovering $2000 worth of gold per day which previously had been going to waste in the slimes. It was the success of this large operation which first brought Mr. Merrill worldwide recognition and acclaim.

After his ten years at Homestake, Mr. Merrill returned to San Francisco and established his office there. This was in 1908. Two years later, he organized The Merrill Co., to make his processes, methods, and equipment available on a world basis. Later, he organized a number of subsidiary companies to handle the manufacture and distribution of various technical equipment and products developed by himself or his associates. He was active in these companies for many years, and was board chairman of The Merrill Co. at the time of his death.

In the field of public service Mr. Merrill was active nationally and locally. During World War I, at the request of his lifelong friend Herbert Hoover, Sr., he accepted assignment in Washington as Chief of the Div. of Collateral Commodities in the Food Administration, serving in that capacity until the end of the war. During World War II his various enterprises were called upon by the Armed Services to extend and vary their endeavors and processes as their part in aiding the war effort.

Mr. Merrill was a vice president of the AIME in 1924, and in that year was awarded the Institute's James Douglas Medal for "distinguished international metallurgical achievement." In 1924 and 1925 he was a member of the Board of Regents of the University of California, serving also as president of the Alumni Assn. In the city of San Francisco he served as chairman of the Community Chest from 1925 to 1927, and later was chairman of the California State Mining Board and the Minerals Committee of the State Chamber of Commerce.

In 1940 Mr. Merrill won an award from the NAM for "distinguished achievement in the field of science and invention, which has advanced the American standard of living." In recent years he held various posts with the U. S. Bureau of Mines.

Mr. Merrill was a member of the University, Engineers,' Pacific Union, and Commonwealth Clubs of San Francisco; the Mining and Metallurgical Society of London; the Australian Institute of Mining Engineers; and the Chemical Metallurgical, and Mining Society of South Africa.

Proposed for Membership
— Metals Branch AIME —

Total AIME membership on Feb. 29, 1956 was 24,331; in addition 2,513 Student Associates were enrolled.

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The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

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Necrology

Date Elected	Name	Date of Death
1939	George H. Anderson	Feb. 16, 1956
1904	George W. Bryant	Dec. 5, 1955
1941	W. J. Felton	Feb. 10, 1956
1919	A. E. Flynn	Feb. 28, 1956
1891	Walter R. Ingalls	Feb. 25, 1956
1954	William H. Johnson	Feb. 19, 1956
1923	Eldred A. Knapp	Feb. 16, 1956
1937	James B. Macelwane	Feb. 15, 1956
1892	Charles W. Merrill	Feb. 7, 1956
1945	Stanley Y. Slocum	August 1955
1955	P. Vogelsang	Feb. 22, 1956

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— Coming Events —

Apr. 2-7, International Union of Crystallography, Madrid, Spain.

Apr. 6-7, AIME, Utah Uranium Subsection, Uranium symposium, Moab, Utah. Reservations should be made with AIME Symposium Committee, P.O. Box 877, Moab, Utah.

Apr. 9-11, AIME, Blast Furnace, Coke Oven, and Raw Materials and National Open Hearth Steel Conferences, Netherland-Plaza Hotel, Cincinnati.

Apr. 9-12, SAE, aeronautic meeting, production forum, and aircraft engineering display, Hotel Statler, New York.

Apr. 10-12, Metal Powder Association, annual meeting and Metal Powder Show, Hotel Cleveland, Cleveland.

Apr. 18-20, National Industrial Research Conference, Armour Research Foundation, Illinois Institute of Technology, Chicago.

Apr. 19, AIME, Cleveland Section, dinner meeting, Hotel Manger, Cleveland.

Apr. 20-21, AIME, New England Regional Conference, Waverly Inn, Cheshire, Conn.

Apr. 22-26, American Ceramic Society, Statler Hotel, New York.

Apr. 26-27, American Insitute of Electrical Engineers, national meeting, Bradford Hotel, Boston.

Apr. 29-May 3, Electrochemical Society, Inc., Mark-Hopkins Hotel, San Francisco.

May 2-5, Association des Ingénieurs Sortis de l'Ecole de Liège, conference on electron microscopy, Liége, Belgium.

May 3-5, AIME, Pacific Northwest Regional Metals and Minerals Conference, Olympic Hotel, Seattle.

May 4, American Association of Spectrographers, annual conference, Chicago.

May 6-9, AIChE, Roosevelt Hotel, New Orleans.

May 7-11, American Welding Society, national spring meeting, Hotel Statler, Buffalo.

May 14-17, Design Engineering Show, Convention Hall, Philadelphia.

May 16, AIME, Western Section NOHC, Rodger Young Auditorium, Los Angeles.

May 22-25, Société de Chimie Physique, annual reunion, Paris, France.

June 3-8, SAE, summer meeting, Hotel Chalfonte-Haddon Hall, Atlantic City, N. J.

June 4-7, Material Handling Institute, show, Public Auditorium, Cleveland.

June 5, AIME, NOHC, Buffalo Section, golf party.

June 13, AIME, NOHC, Pittsburgh Section, golf party, Pittsburgh Field Club.

June 16-25, Fifth World Power Conference, Vienna, Austria.

June 17-22, ASTM, annual meeting, Hotel Chalfonte-Haddon Hall, Atlantic City.

June 22-July 6, International Machine Tool Exhibition, Olympia, London, England.

Aug. 23-25, National Council of State Boards of Engineering Examiners, Hotel Statler, Los Angeles.

Sept. 9-12, AIChE, William Penn Hotel, Pittsburgh.

Sept. 16-22, ASTM, Pacific Coast meeting, Statler Hotel, Los Angeles.

Sept. 26-28, AIME, Rocky Mountain Minerals Conference, Salt Lake City.

Oct. 8-10, AIME, IMD fall meeting, Hotel Carter, Cleveland.

Dec. 9-12, AIChE, annual meeting, Statler Hotel, Boston.

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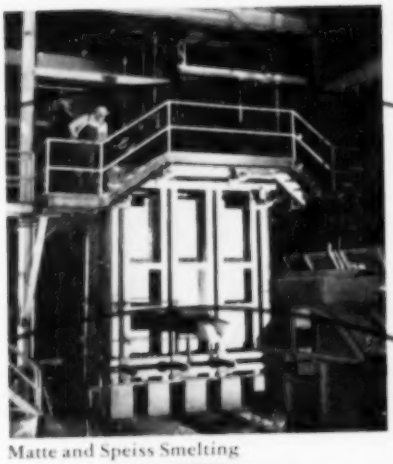

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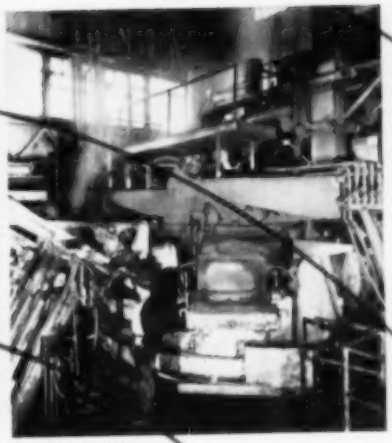

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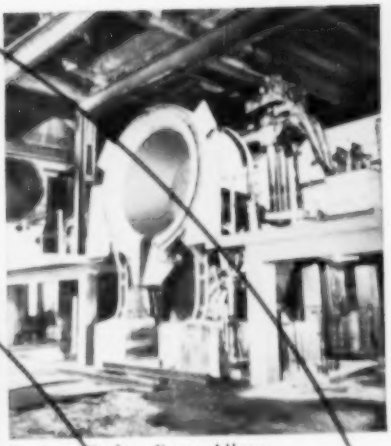

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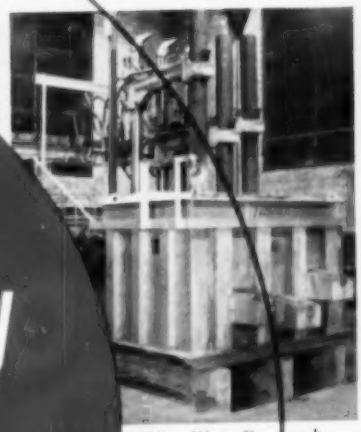

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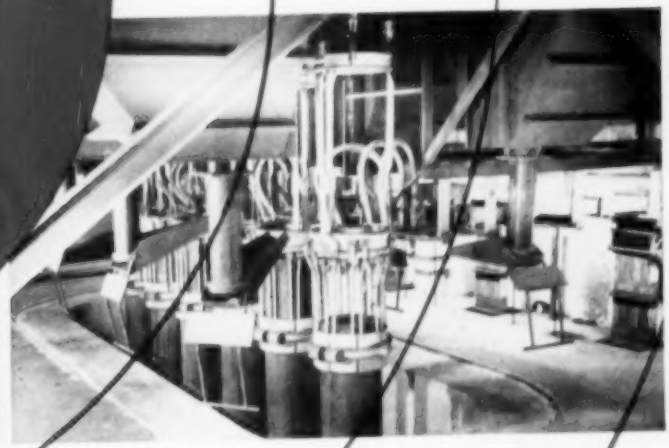

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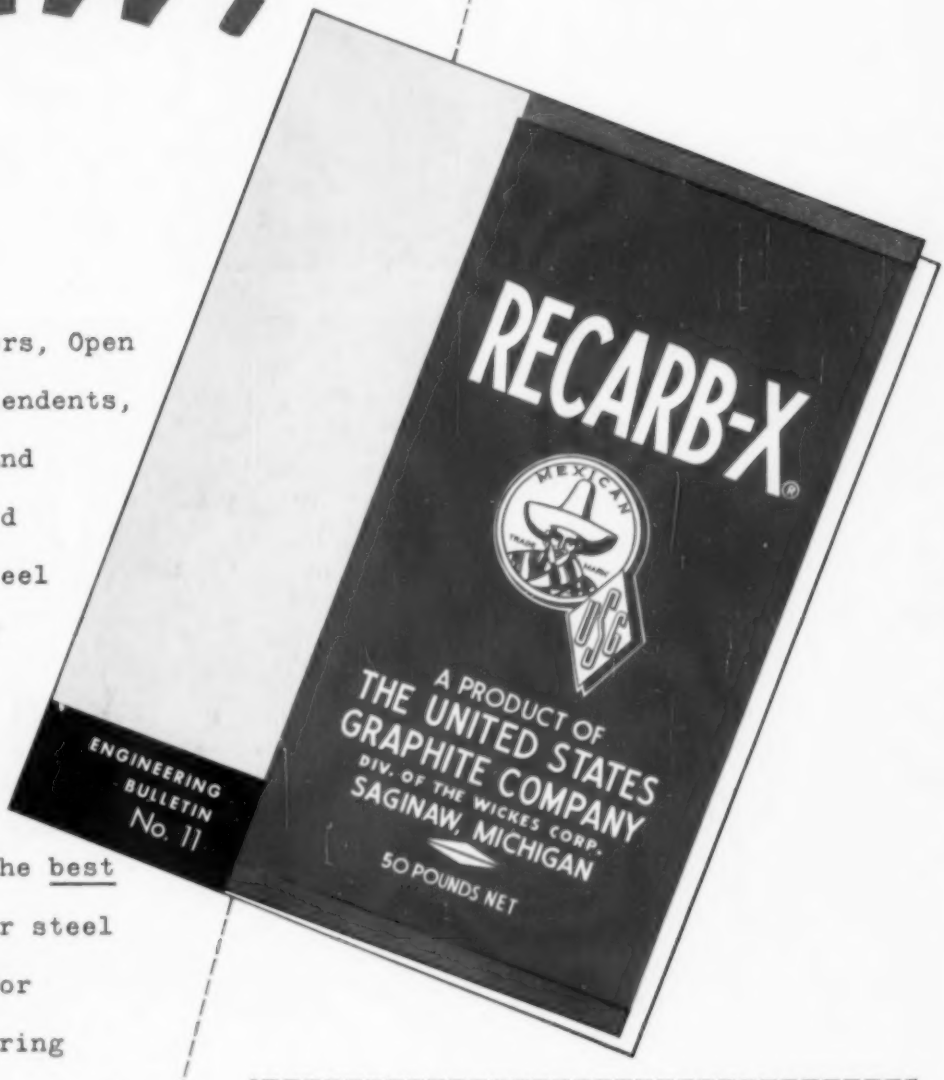

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